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ABSTRACT

Two experiments investigated developmental aspects of the two components of scientific reasoning: induction and deduction. In the first experiment, 98 subjects, ages 5 through 11, inductively identified four silhouetted pictures by removing, one at a time and in any sequence, as few covering pieces as possible. Results indicated that: (a) the ability to utilize incomplete information improved with increased age, but with a performance plateau between ages 8 and 11; and (b) the ability to expose information improved with age while the number of verbalized hypotheses remained relatively constant. In the second experiment, 120 subjects, ages 9 through 14, either utilized their own (Master) exposure sequence or followed (slaved) that of an age, sex, and IQ paired subject to inductively identify six, 36-cell symmetrical patterns of X's and O's. Deductive cell predictions improved with increased age and were similarly accurate for both subject groups. For pattern inductions, which also improved with increased age, slaved subjects generally hypothesized earlier, more often, and more correctly with less information than did master subjects. Results are analyzed from cognitive and developmental orientations, and implications are offered for research and educational practices. (Author)

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DEVELOPMENTAL ASPECTS OF SCIENTIFIC REASONING

September 1972

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CHAPTER I

INTRODUCTION

Rationale

By the nature of our environment, we are often confronted with incomplete information. An essential process in understanding this information is the invention or generation of a classificatory scheme for the existing plus appropriate additional information. This knowledge generation process, hereafter known as induction, is reflected in the entire range of human abilities: man constantly bases hypotheses on fragmentary evidence.

An overall conclusion by Cox (1972) was that this knowledge generation process has important research and educational implications which demand further investigation. Even so, few curricula attempt to teach induction processes and those that do generally exist without supportative research findings. Also, induction as a trainable process is often ignored in favor of its more easily investigated counterpart: deductive reasoning.

The purpose of this study was to investigate various developmental aspects of inductive reasoning. The overall eventual goal is to build a systematically derived knowledge base on inductive reasoning. Such an investigation immediately falters, however, on describing the nature and operational characteristics of inductive reasoning. The ambiguity and conceptual imprecision of induction as a psychological process is illustrated in the following sections (condensed from the paper as Abstract A, "Inductive Reasoning--A Literature Review and Empirically Oriented Conceptualization," Cox, 1972).

Related Conceptualizations

Conceptualizations vary from philosophical or nonempirical to pure empiricist orientations. This section briefly reviews such conceptualizations and proposes a definition of inductive reasoning within the context of problem solving or scientific reasoning.

Characteristics of inductive reasoning. Most conceptualizations of inductive reasoning reflect both the ambiguity of terms and the variance of early philosophical orientations. Terms such as insight, intuition, guessing, creativity, and probability are often used interchangeably with induction. Westcott (1968) notes that on a continuum of intuition, empirical induction exists opposite from the acquisition of knowledge as perfect truth. Philosophically, arguments vary from portraying induction as a special case of deduction (Spearman, 1923) to adamant denials of its very existence (Popper, 1959).

For the proponents, statements more specific than the particular-to-general theme characterize the nature of induction. For example, summary statements are not inductive in nature unless they add something more to the premise conditions (Medawar, 1969). An essential quality of induction is the "going beyond the information given (Bruner, 1957)" to produce hypotheses or statements wider than the conditions from which they were derived.

The evaluation of inductive statements, unlike deduction, does not rely on explicit, formal rules or structures. Rather, the underlying assumption of all forms of induction is a reliance on the principle of the uniformity of nature. It is the patterns and periodicities of nature which form the basis of prediction. Therefore, inductively established laws cannot be certain but are only more or less probable (Brennan, 1957).

Because of this empirical basis, induction, again unlike deduction, is concerned with the material truth of premises. Verifiable and observable methods exist to establish the truth value of generated laws or hypotheses. In fact, the specific problem of induction, according to Cohen and Nagel (1934), is to determine to what extent the samples are fair representations of an entire class to which they belong.

Taken together, the two complementary processes of induction and deduction comprise the scientific method. A scientist attempting to bring order to a body of knowledge supposedly (Wallach, 1967) invents or generates a theory and then proceeds along a deductive path to the proving ground provided by his experimental predictions. The first phase, induction, includes the processes of generation, invention, creation, and other processes best characterized as knowledge expansion efforts. The second phase, deduction, is generally characterized (e.g., Medawar, 1967, 1969) as a logical process of testing, deriving, and inferring consequences of the first phase results.

The importance of inductive reasoning processes is illustrated via Mendeléef's invention of the Periodic Table of Chemical Elements. From only partial information about known chemical elements, Mendeléef hypothesized or induced that element properties repeated themselves periodically after each seven elements. He then deductively tested his hypothesis by not only completing the Table for all known elements but by predicting properties of, as yet, undiscovered elements and by demonstrating that properties of certain elements had been incorrectly established. While this is only one example of the productive results of scientific reasoning, it clearly and dramatically indicates the critical nature of generational processes.

Psychological conceptualizations of induction have often emphasized acts of generation or creation. Torrance (1967) defines creativity to include the sensitivity to gaps in knowledge and the formulation of hypotheses; Guilford (1967) emphasizes transformed products; Bartlett (1958) mentions gap-filling processes; and Westcott (1968) asserts that intuition is "the process of reaching a conclusion on the basis of little information which is normally reached on the basis of significantly more information (p. 41)." A similar definition as proposed by Cox (1972) is used in this study.

Definition of inductive reasoning. Induction is defined as "the generation of a reportable hypothesis from only some members (as given) of a class, scheme, or pattern to describe the whole or at least some larger portion thereof (p. 26)." Cox (1972) specifically emphasizes that induction is a function of stimulus incompleteness, thus automatically eliminating instances where the underlying rule explains the existing data only (e.g., "what is the rule that combines the following numbers . . . ?").

Actually, to achieve operational validity, induction is considered within very specific environmental constraints: the scientific method is the framework in which induction exists. Boundary conditions for investigating induction are as follows. The task situation should involve spatial rather than temporal patterns. While evidence accumulates over time, data are analyzed in spatial rather than temporal schemes. A second consideration is the use of symbols rather than pictures. While initial investigations might begin with pictorial stimuli, ultimately more sophisticated stimuli should be utilized to progress from perceptual, often memory-based skills, to generational and conceptual skills. A third consideration is that induction involves proposing a rule to handle the data but does not involve describing (often deductively) the appropriate stimulus characteristics.

Few research efforts investigate induction, however, as is evident in the following section. Even so, a rationale exists (other than the requirement for more research) for studying inductive processes, especially on a developmental basis.

Related Research

While Polya (1954) calls for the teaching of guessing and the Woods Hole Conference on Education (Bruner, 1963) notes the importance of developing intuitive thinking, curriculum research and development efforts have generally ignored these and similar pleas. Few educational programs specifically emphasize the teaching of inductive reasoning. Some curricula do require subjects to perform hypothesizing and inferring operations but the specific process of induction is not conceptually isolated and examined. The practice of constructing curricula without the benefit of research support is somewhat understandable considering the lack of experimental evidence available.

Experimental studies. Stimulus materials used in available research studies are generally either incomplete pictures (Gollin, 1960, 1961, 1962, 1965; Messick & Hills, 1960; Mooney, 1957a, 1957b, 1957c; Smock, 1955, 1957; Westcott, 1968) or serial completion tasks (Simon & Kotovsky, 1963; Simon & Sumner, 1968; Westcott, 1968). Elkind, Anagnostopoulou, and Malone (1970) suggest that identification of incomplete pictures occurs instantaneously and with a single fixation, and Gollin suggests that training on incomplete forms is more facilitating than training on complete pictures. On serial completion tasks, people apparently have a strong tendency to discover and predict temporal patterns (Simon & Sumner, 1968) and to ignore independent trials in a search for patterns, either real or imagined (Beach, 1964).

Psychological variables related to induction and pattern seeking include reflection-impulsivity, epistemic curiosity, and cognitive strain. Specifically, children who are conceptually reflective tend to make fewer inductive reasoning errors than do conceptually impulsive children (Kagan, Pearson, & Welch, 1966); epistemic curiosity describes a quest for knowledge to relieve cognitive discrepancies (Berlyne, 1962); and cognitive strain (Bruner et al., 1958) is a determining factor in selecting information processing strategies.

Psychological models suggest that induction involves the detection of certain properties and the formulation of a tentative model or solution (Johnson, 1955, 1961; Simon & Kotovsky, 1963). Fletcher (1969), in his model of cognitive operations, labels these processes, respectively, transformation and generation, and Cox (1972) similarly proposes a dual-stage (cognitive encoding and hypothesis generation) theory of induction. Klahr and Wallace (1970) note the developmental tractability of the Template Building and the Simon-Kotovsky models of inductive reasoning; from data on a 5-year-old subject, the former is apparently a developmental precursor of the latter.

Developmental considerations. Developmental studies on inductive reasoning should provide the major impetus for inductive curriculum development. However, a complete picture of developmental as well as mature aspects of inductive reasoning is lacking. The relatively small number of investigations thus far have produced only a partial understanding of the development of inductive inference. Developmental research (i.e., Inhelder & Piaget, 1958; Maier, 1936) suggests that not until approximately age seven do children begin to reason systematically and independently of immediate environmental restraints. As expected, younger children usually demand more information and make more errors on perceptually based stimuli than do older subjects (Cox & Fletcher, 1971; Gollin, 1960; Westcott, 1968).

Mindful of the need to solidify a psychological conceptualization of induction, Cox and Fletcher (1971) initiated research concerned with the development of inductive reasoning in children. The immediate goal was construction of a systematically organized knowledge base for ultimate utilization in curriculum development efforts. Their study is of specific interest to this paper.

Problem Formulation

In their study, Cox and Fletcher required twenty subjects, in each of the 4-, 6-, 8-, and 10-year-old age groups, to identify picture stimuli on the basis of less than complete information (inductive reasoning). Unique to their study, however, was the procedure which allowed subjects to determine and use their own information gathering strategies. That is, subjects removed, in any desired order and one at a time, picture covering pieces (48 total) in an effort to identify the picture with as few removals as possible. Of the six dependent variables analyzed, four were of special theoretical importance for their developmental progression. That is, while the efficiency of removing pieces on target (the picture per se) and the rate of verbalizing hypotheses improved monotonically with increased age, the measures indicating total number of pieces removed and proportion of picture exposed before correct identification exhibited a performance plateau between ages six and eight.

Nonmonotonic developmental performance trends for children have also been recorded by other researchers. Westcott (1968), like Cox and Fletcher, found an increased demand for information by children approximately eight years old than by adjacent age groups. At this approximate age range, Shapiro and O'Brien (1970) found an asymptotic function in the deductive ability to recognize logical necessity, and Torrance (1961) found a decreased performance in number of questions asked on tests of creativity. However, few explanatory reasons for the nonmonotonic trend are offered. In fact, this author is unable to find evidence from Piagetian theory to support performance decrements as a function of stage transition.

In summary, induction is a vital process in man's acquisition of knowledge. However, the small amount of research information available is often perceptually-based and is largely irrelevant to curriculum development needs. Moreover, the variable effects of stimulus and organismic variables and the trainability of inductive reasoning are all unknown factors. The overall conclusion is that investigations are needed into these and other issues especially appropriate to educational practices.

In an effort to clarify the initial Cox and Fletcher findings and to continue building a knowledge base, the following two studies were conducted. Specific issues investigated were the inductive performance plateau (Experiment I) and a separation of inductive and deductive performances on arbitrary symmetrical patterns (Experiment II).

CHAPTER II

EXPERIMENT I

Statement of Problem

This study analyzed the determinants of the performance plateau observed in the earlier Cox and Fletcher Study. For most part, the rationale for analysis is derived from Weir (1964) who suggests that

> the 7- to 10-year-old is at a point in development where his ability to generate complex hypotheses and employ complex search strategies is growing at a faster pace than his information processing ability which catches up only at a later stage (p. 481).

The abilities of hypothesizing, strategy employment and information utilization were represented by the following scores in the Cox and Fletcher study. The Verbalization Rate score, defined as the rate of verbal hypotheses offered, represents the hypothesizing behavior. This score increased monotonically with increased age. The Efficiency score, defined as the ratio of pieces removed on target divided by total number of pieces removed, represents the complex strategy employment behavior. This score also increased monotonically with increased age. The Information score, defined as the proportion of picture exposed before correctly named, represents the information utilization behavior. This score, however, did not increase monotonically with age. That is, while a general improvement with increased age was recorded, a consistent and reliable plateau in performance existed between ages six and eight. The results, especially the plateau effect, are similar to findings by Westcott (1968) and appear compatible with the Weir explanation of differentially developing abilities.

However, compatibility with the Weir hypothesis is not perfect. Weir suggests that the level of stimulus complexity is a functional determinant of the age range at which the performance differential appears. In other words, with increased or decreased task complexity, the plateau will occur developmentally earlier or later, respectively, as the capacity of subjects to make use of information is exceeded. Given that the pictures in the Cox and Fletcher study were of differential difficulty (F ratio $p < .001$), the Weir explanation would lead to predicting a significant Age by Picture interaction (plateau shift with regard to age). However, the plateau shift or interaction effect was not present. A distinct possibility is that the pictures were insufficiently variable in difficulty to produce a plateau shift.

This experiment, then, utilized new and more variable stimuli and more age groups to replicate and explicate the apparent information utilization plateau reported in the Cox and Fletcher study.

Method

Subjects

Subjects were randomly selected from classes in the Florida State University Laboratory School where admission procedures ensure proportional demographic representation. Ninety-eight subjects, seven males and seven females in each of the 5-, 6-, 7-, 8-, 9-, 10-, and 11-year-old age groups, successfully completed the experimental tasks. Racial composition of the groups was 1 black and 13 whites for age 10; 2 blacks and 12 whites for ages 5, 8, 9, and 11; 3 blacks and 11 whites for age 6; and 4 blacks and 10 whites for age 7. Mean age and range in months for each age group was as follows: 5-year-olds ($\bar{X}$ = 60.2, range 55 to 66); 6-year-olds ($\bar{X}$ = 73.1, range 68 to 77); 7-year-olds ($\bar{X}$ = 82.5, range 78 to 88); 8-year-olds ($\bar{X}$ = 96.6, range 90 to 102); 9-year-olds ($\bar{X}$ = 108.1, range 104 to 11[illegible]); 10-year-olds ($\bar{X}$ = 119.5, range 115 to 124); and 11-year-olds ($\bar{X}$ = 130.4, range 127 to 138).

Apparatus and Stimuli

Test apparatus (see Figure 1) was a shallow open-ended wooden box (10 in. width x 12 in. length x 1 in. depth) with a clear plexiglass top. Totally covering the plexiglass was a 6 x 8 matrix of 48 removable wooden pieces (1 3/8 in. x 1 3/8 in. x 1/4 in.). A small peg-like knob on each piece facilitated removal. Picture stimuli (see Figure 2) were inserted (and removed) under the plexiglass through the open end and

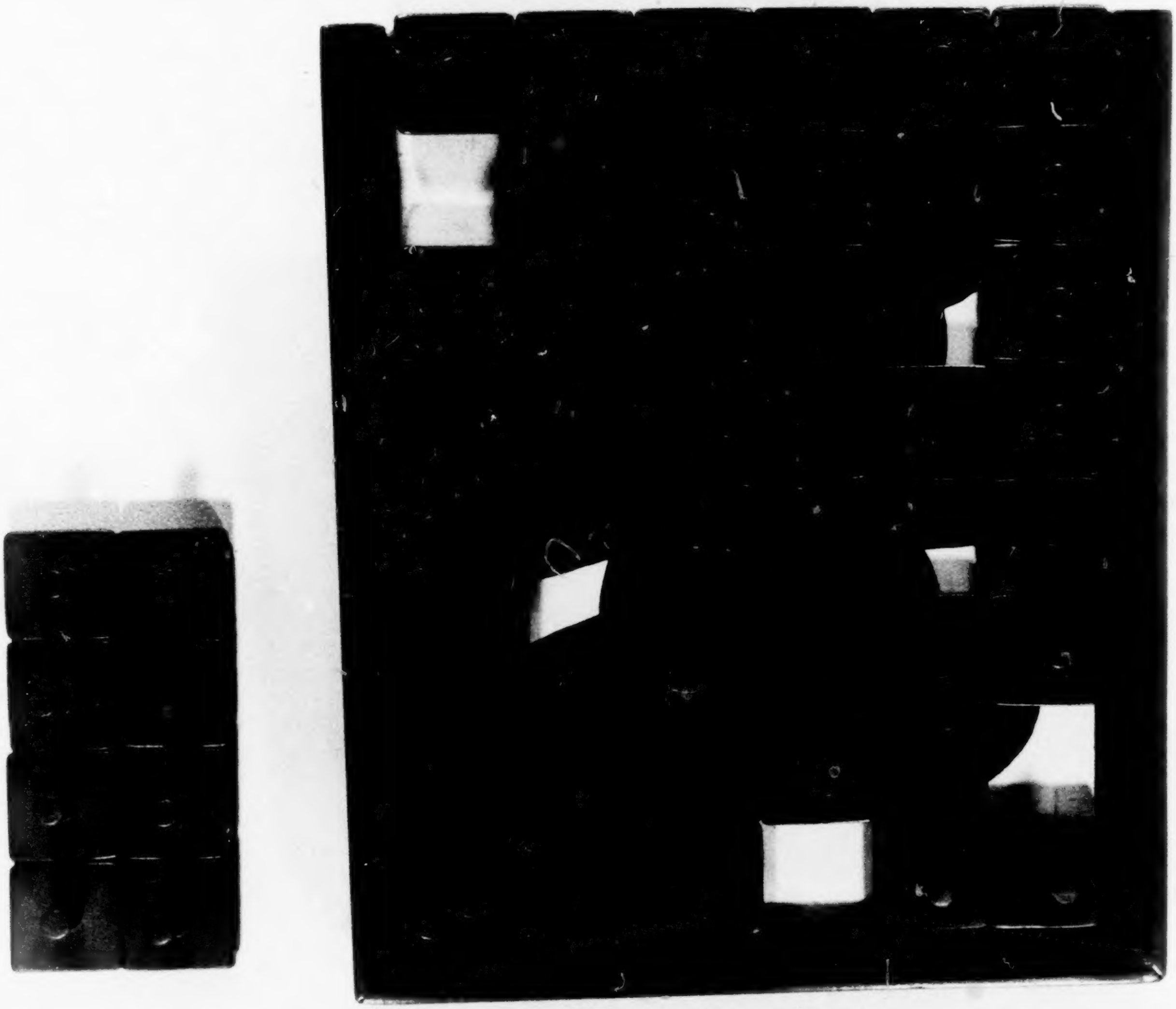
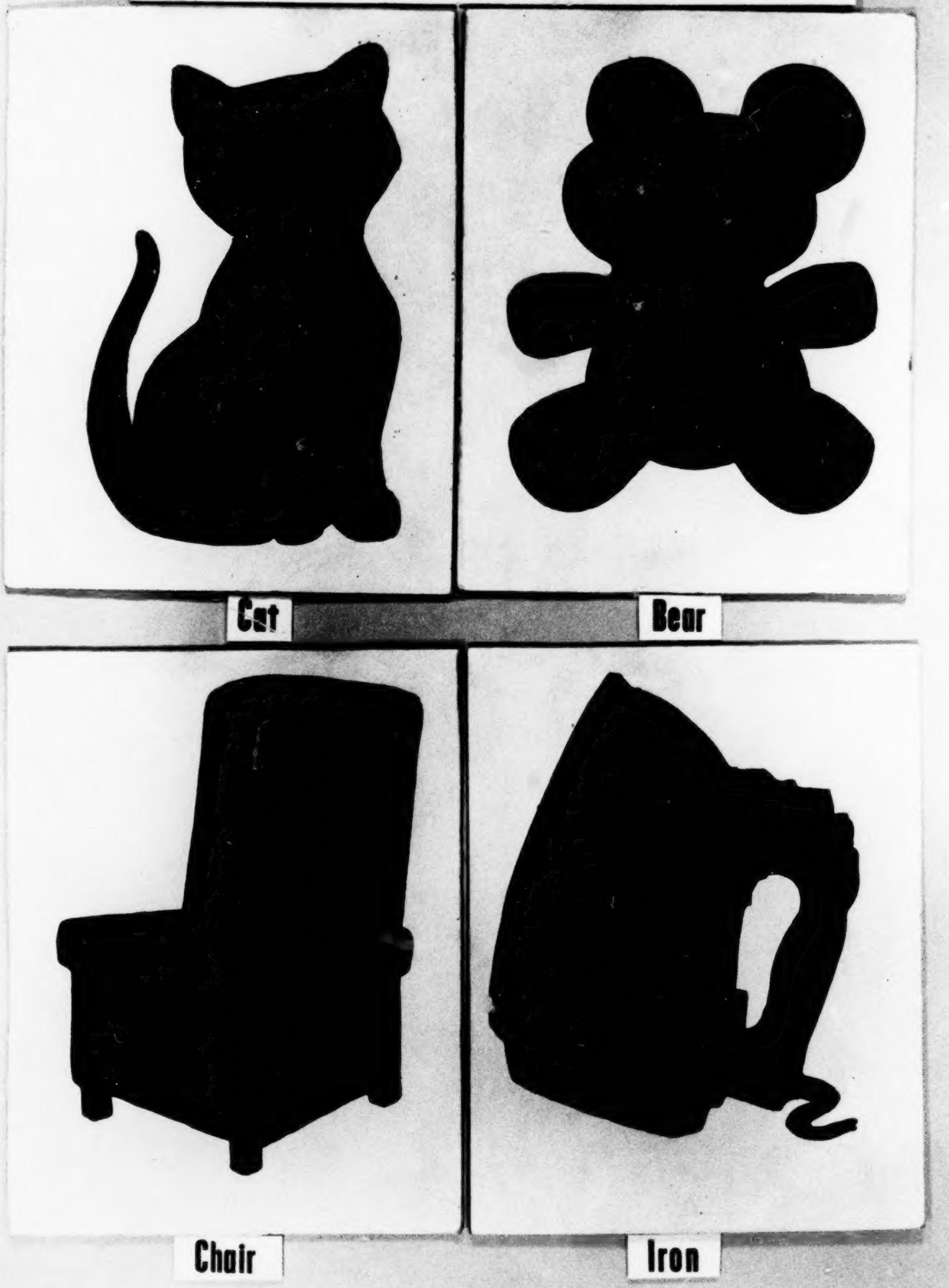


Fig. 1. Test instrument used in Experiment I.

Fig. 2. Four picture stimuli used in Experiment I



Cat

Bear

Chair

Iron

became gradually more exposed upon removal of each covering piece.

The stimuli were four, 8 1/2 x 11 in., reproduced, shaded (blackened) coloring book pictures (cat, bear, chair, and iron). Shaded or silhouette forms were selected to eliminate obvious identifying cues and were appropriately adjusted to achieve equality in the number of picture-covering pieces (cat--35, bear--36, chair--36, and iron--35). This 74% piece covering ratio (number of pieces covering the picture divided by total pieces--48) was selected to promote stimulus difficulty through use of a large quantity of covering pieces while still providing an ample number of off-target pieces. Finally, stimuli were approximately equally spaced on an easy to difficult continuum. From the results of an initial pilot study, seven pictures were selected and tested on 13 children and 10 adults for obtaining the final four pictures.

Procedure

Both the experimenter and assistant were introduced to classes (from which Ss were randomly drawn) and allowed to interact with Ss prior to testing. Testing was administered in small, quiet offices in the same building and conducted in a game playing atmosphere.

Prior to admitting S, the four stimuli were randomly ordered and placed under the matrix covered plexiglass. The pretest was then administered to determine S's ability to follow test directions.

Pretest. Picture stimulus for the pretest was a leaf, also selected from a coloring book and similarly shaded. Two pieces from the test apparatus were placed on the leaf picture in the following manner: one on the leaf, and one on the paper but not on any part of the leaf. Two part directions were then administered:

1. "Pick up the piece on the leaf."
2. "Pick up the piece not on the leaf."

After each direction, the removed piece was returned to its previous leaf position. The pretest identified Ss who could operationally define the concepts "on" and "not on." Passing both parts was mandatory for going to the test session.

Test session. Prior to test administration, S was shown the test instrument and asked what pictures were being used. Answers indicated that Ss were not communicating the nature of the experiment to each other. The following verbal directions were then given:

> There is a new picture under the pieces. It will not be the leaf or any of these other examples but will also be a black picture on white paper. You have to pick up the pieces, one at a time, that are on the picture and tell me what the picture is as soon as you can. Remember, you want to correctly name the picture before too many pieces are removed. Okay, begin.

When mentioned in these directions, six other pictures (duck, bird, leaf, house, plane, elephant) were immediately shown to S. These pictures, representing classes of animate and inanimate objects, demonstrated the range of stimulus materials that were used.

As S proceeded, pieces were not replaced but laid aside. On every fourth instrumental response (piece removed), S was asked (but not required) to name the picture. After each verbalized hypothesis, no clue was given as to its correctness. Whenever correct, the S was always allowed to remove four additional pieces prior to terminating. Even then, termination occurred only when two correct hypotheses were given in sequence, thus avoiding recording instances of correct but randomly guessed identifications. Subject's piece removal sequence and verbal hypotheses were recorded on a protocol sheet designed to match the 6 x 8 matrix.

After the second (consecutive) correct naming or after the picture was completely exposed, pieces were replaced on the instrument, recovering the stimulus picture. The picture was removed and S was asked to give its name. This name was used to determine the total elapsed time and "correct" picture name for Ss who offered related or more specific names than required of a generic concept, e.g., sofa or couch instead of chair. Five Ss, unable to name the stimuli, were not included in the experimental analysis.

Instructions and procedures were then repeated for the other three stimuli. Upon completion of all four stimuli, S was urged not to divulge experimental procedures.

Each subject received, in a 15-30 minute session, the pretest, all four randomized pictures, and questions and advice concerning advanced knowledge of the experiment. The order of testing classes and subjects within each class was completely randomized.

Dependent Measures

The following scores were computed and analyzed:

1. Picture Identification score--defined as the number of pieces removed before correctly naming (first of correct pair) the picture.

2. Verbalization Rate score--defined as the number of picture identity hypotheses divided by the number of pieces removed (Picture Identification score).

3. Removal Efficiency score--defined as the number of pieces removed on any shaded portion before correctly naming the picture divided by the total number of pieces removed.

4. Contour Efficiency score--defined as the number of pieces removed which revealed the stimulus contour before correctly naming the picture divided by the total number of pieces removed. And,

5. Information Utilization score--defined as the number of picture revealing pieces removed prior to correct identification divided by the total number of pieces which cover each particular picture (Cat--35, Bear--36, Chair--36, Iron--35).

Design and Analysis

A 7 x 2 x 4 (Age by Sex by Stimulus) design was used. Seven males and seven females in each age group received four stimulus pictures as repeated measures.

A 7 x 2 x 4 analysis of variance was conducted for each dependent measure. All subsequent t tests were two-tailed and utilized a pooled error term from the ANOVA. A positive bias correction was applied to those degrees of freedom used to test repeated measure factors (Greenhouse & Geisser, 1959). The alpha level for statistical significance was .05.

Results

Analysis of variance F ratios are reported in Table 1. Both Picture and Age factors were significant for all but two dependent measures. A detailed discussion of each analysis follows in appropriate sections.

Picture Identification Score

Picture Identification score is defined as the number of pieces removed before correctly naming the picture. The score is a gross measure of subjects' performance since the count includes those pieces removed which both covered and did not cover the shaded picture. Analysis of variance revealed significant Picture and Age factors (see Table 1).

As depicted in Table 2, the mean scores for all pictures generally improved with increased age. Subsequent t tests revealed no significant performance difference between adjacent age means. However, mean scores indicated significantly more pieces removed for subjects 5 and 6 than for subjects age 8 ($t = 2.59$, $df = 84$, $p < .05$; $t = 3.56$, $p < .01$), age 9 ($t = 2.30$, $p < .05$; $t = 3.27$, $p < .01$), age 10 ($t = 3.07$, $p < .01$;

TABLE 1

Summary of F Values (ANOVA) for Experiment I

Source	df	Dependent measures				
		1	2	3	4	5
Between Ss	97					
Age (A)	6	6.13***	2.15	6.96***	1.41	4.14***
Sex (G)	1	< 1.00	1.00	1.67	< 1.00	< 1.00
A x G	6	1.35	2.26*	< 1.00	1.02	1.48
Ss within AG	84					
Within Ss	294					
Pictures (P)	3	179.40***	28.33***	19.62***	40.68***	162.82***
P x A	18	2.19	1.76	1.75	1.29	2.44
P x G	3	< 1.00	4.38*	< 1.00	1.73	1.06
P x A x G	18	1.81	< 1.00	< 1.00	< 1.00	1.70
P x Ss within AG	252					

* p < .05
*** p < .001

1. Picture Identification score
2. Verbalization Rate score
3. Removal Efficiency score
4. Contour Efficiency score
5. Information Utilization score

TABLE 2

Age and Stimulus Means for each Dependent Measure in Experiment I

Scores	Ages							Stimuli			
	5	6	7	8	9	10	11	Cat	Bear	Chair	Iron
1. Picture Identification	27.75	29.68	26.20	22.57	23.16	21.63	20.11	13.88	19.08	25.39	39.42
2. Verbalization Rate	.09	.09	.11	.11	.10	.14	.12	.14	.12	.10	.08
3. Removal Efficiency	.81	.84	.83	.86	.91	.95	.95	.91	.90	.88	.82
4. Contour Efficiency	.58	.62	.57	.60	.57	.63	.62	.64	.67	.48	.61
5. Information Utilization	.62	.68	.60	.53	.57	.55	.52	.35	.46	.62	.89

t = 4.03, $p < .01$), and age 11 (t = 3.83, $p < .01$; t = 4.79, $p < .001$). Existence of a performance plateau is suggested between ages 5 and 6 and between ages 8, 9, and 10.

Pictures, as selected, maintained the easy to difficult rank order of cat, bear, chair, and iron, and elicited significantly different performances ($p < .001$). Mean score for each was as follows: cat--13.9, bear--19.1, chair--25.4, and iron--39.4.

No other factors were significant. In fact, performance for males ($\overline{X}$ = 24.5) differed only slightly from that of females ($\overline{X}$ = 24.3).

Overall, the findings add little to understanding the hypothesized differential ability growth rate. Understandably so, however, since this score, as mentioned earlier, is only a gross indication of subject performances. A closer examination of hypothesis-appropriate scores follows.

Verbalization Rate Score

Verbalization Rate score is defined as a proportion: the number of verbal responses to the total number of pieces removed (Picture Identification score) before correctly identifying the picture. The number of verbal responses includes both those requested but not required of the subject on every fourth piece removed and those freely offered by the subject. However, since subject-initiated responses seldom occurred, the maximum expected score for any subject (on any picture) was .25 or 1 verbal response for every fourth piece removed. Again, as with the Cox and Fletcher study, this score is interpreted as a measure of subjects' hypothesizing ability. Analysis of variance (see Table 1) indicated a significant Picture factor, Age by Sex interaction, and Sex by Picture interaction. No other factors (including Age) nor interactions were significant.

The significant Age by Sex interaction is illustrated in Figure 3. While indicating a generally parallel trend, performance curves at ages 8 and 11 reflect an increasing rate (from the previous score) of verbalizations for females and a decreasing rate of verbalizations for males. However, the greater number of verbalizations for females than for males is significant only for the 8-year-olds ($\underline{t} = 2.42$, $\underline{df} = 84$, $\underline{p} < .05$). An interesting question is whether the male-female performance differences would increase, stabilize, or decrease for 12-year-old subjects. Actually, the similarity that occurs for the two curves when shifting the females' scores one age to the left (decreased) or the males' scores one age to the right (increased) suggests differentially developing abilities.

Discussion of the Picture factor is most appropriate in relation to the Sex by Picture interaction. Figure 4 illustrates the differential scores for male and female subjects on the four stimuli. While the rank order of cat, bear, chair, and iron did not change, the mean differences between the ranked pictures were not the same for males and females.

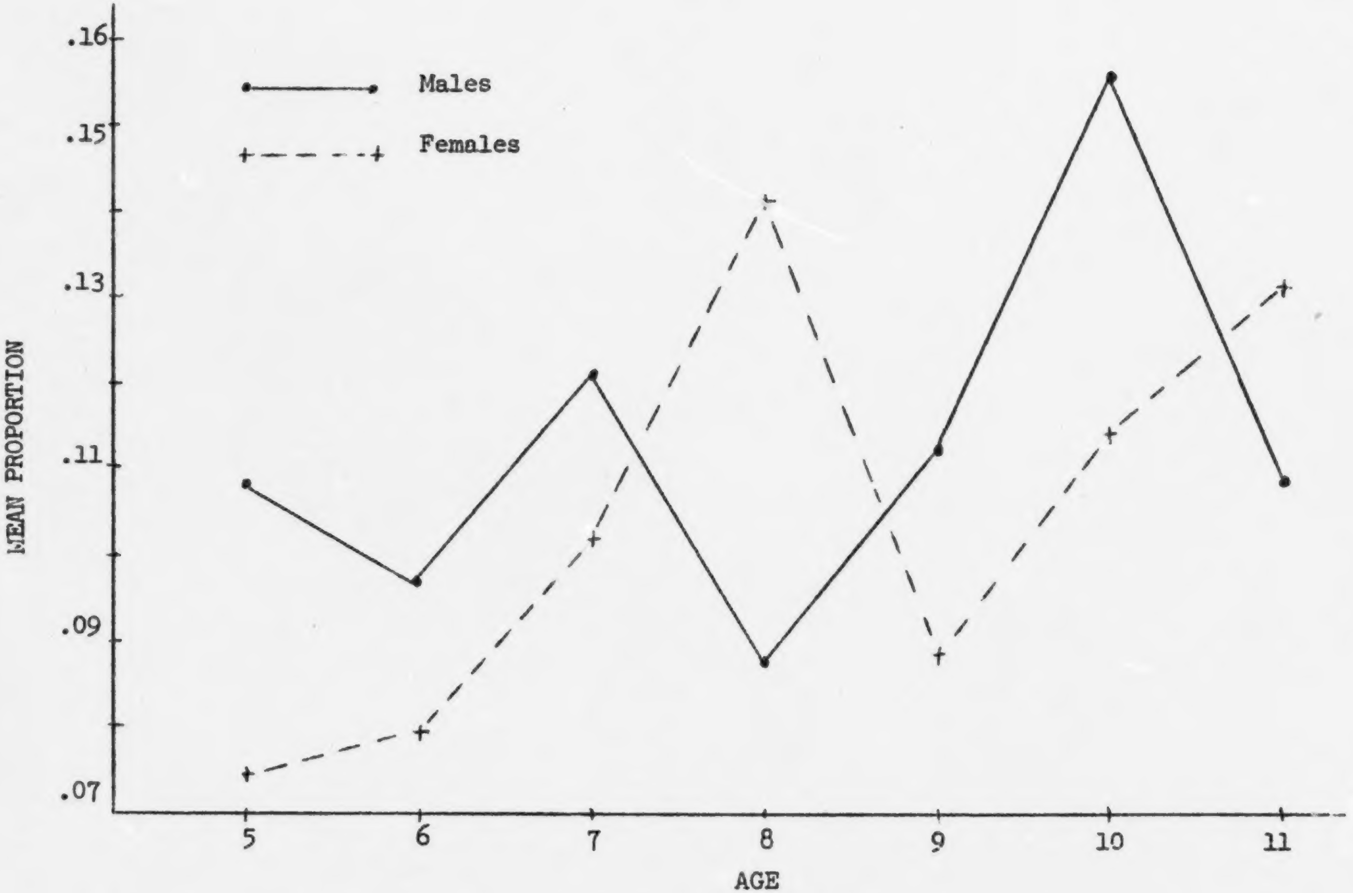


Fig. 3. Verbalization Rate scores for males and females in Experiment I.

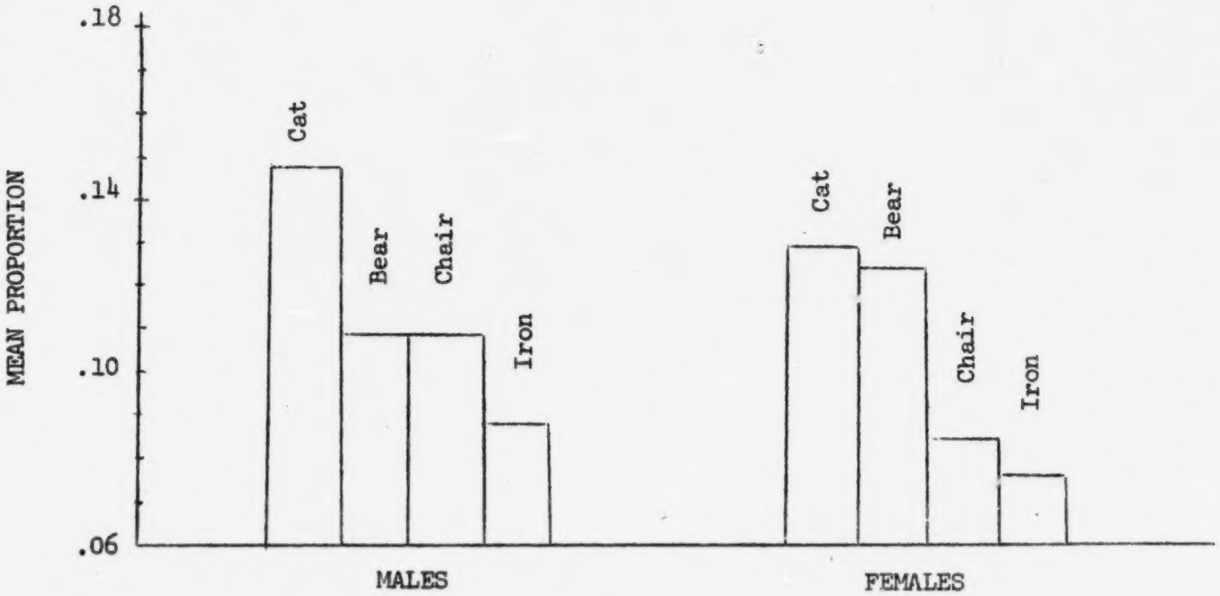


Fig. 4. Verbalization Rates scores for males and females on the four stimuli used in Experiment I.

For males, cat ($\underline{\bar{X}} = .15$) elicited more verbalizations ($\underline{t} = 4.26$, $\underline{df} = 252$, $\underline{p} < .001$) than did bear ($\underline{\bar{X}} = .11$), which was equal to chair ($\underline{\bar{X}} = .11$). Chair, in turn, elicited more verbalizations ($\underline{t} = 1.98$, $\underline{p} < .05$) than did the iron picture ($\underline{\bar{X}} = .09$). Performances of females differed from those of males so that, this time, the middle two stimuli, bear ($\underline{\bar{X}} = .13$) and chair ($\underline{\bar{X}} = .08$) differed significantly ($\underline{t} = 4.15$, $\underline{p} < .001$). Scores for cat ($\underline{\bar{X}} = .13$) and bear, and scores for chair and iron ($\underline{\bar{X}} = .08$) did not differ significantly ($\underline{t} = .45$; $\underline{t} = .65$).

The following two sections examine subjects' piece removal efficiency. First, the efficiency of removing pieces on any part of the shaded picture is examined, followed by an analysis of contour (only) exposure behavior.

Removal Efficiency Score

The Removal Efficiency score is defined as the ratio of: pieces removed on the shaded portion divided by total pieces removed (Picture Identification score) before correctly naming the picture. This score is an indication of how well subjects followed the directions to remove pieces on the picture; hence, to what extent subjects optimally exposed the stimulus. Higher proportion (or percentage) scores indicate more efficient removal behavior (but not necessarily better identification behavior). Analysis of variance indicated, as with the Picture Identification score, only significant Age and Picture factors (see Table 1).

As depicted in Table 2, age related performance increased from 81 to 95% efficiency. Except for the slight decline in scores (84 to 83%) between ages 6 and 7, picture revealing performance increased monotonically with increased age. Performance for subjects age 9, 10, 11 was significantly more efficient than for subjects age 5 ($t = 3.22$, $df = 84$, $p < .01$; $t = 4.54$, $p < .001$; $t = 4.41$, $p < .001$), age 6 ($t = 2.38$, $p < .05$; $t = 3.70$, $p < .01$; $t = 3.56$, $p < .001$), and age 7 ($t = 2.59$, $p < .05$; $t = 3.92$, $p < .001$; $t = 3.78$, $p < .001$). Performance for 8-year-old subjects was not significantly different from the higher (ages 9, 10, and 11) or the lower (ages 5, 6, and 7) efficiency groups.

As with both the Picture Identification and Verbalization Rate scores, the ranking of picture means remained cat ($\bar{X} = .91$), bear ($\bar{X} = .90$), chair ($\bar{X} = .88$), and iron ($\bar{X} = .82$). However, adjacent picture mean scores differed significantly only for chair and iron ($t = 4.90$, $df = 252$, $p < .001$). All nonadjacent pictures differed significantly at least at the .05 level.

Sex was not a significant factor; males ($\bar{X} = .87$) and females ($\bar{X} = .89$) performed similarly. Also, all interactions were nonsignificant.

Since the pretest supposedly admitted only those subjects who could operationally distinguish between removing pieces on versus not on the picture, this score apparently indicates subjects' abilities to perform as required. For all practical purposes, subjects' performances improved monotonically with increased age. To possibly obtain a more refined indication of piece removal efficiency, the following score was computed.

Contour Efficiency Score

Contour Efficiency score is defined as the ratio of pieces removed on the stimulus contour divided by total pieces removed (Picture Identification score) before correctly naming the picture. This score represents subjects' performances in exposing the contour, possibly resulting from some optimal removal strategy. As with the more inclusive measure, Removal Efficiency score, higher scores indicate more efficient behavior (for revealing stimulus contour). Analysis of variance indicated that, unlike all previous scores, Picture was the only significant factor (see Table 1).

The age related scores were not significantly different. From Table 2, it is obvious that subjects between ages 5 and 11 performed with similar efficiency (58 to 63%).

As with all previous measures, the Picture factor was significant. However, the rank order of cat, bear, chair, and iron did not occur. From most to least contour exposed, the means ranked as follows: bear ($\bar{X} = .67$), cat ($\bar{X} = .64$), iron ($\bar{X} = .61$), and chair ($\bar{X} = .48$). Significant differences among adjacently ordered pictures existed only between the iron and chair ($t = 7.02$, $df = 252$, $p < .001$) while all nonadjacent pictures differed significantly at least at the .05 level as with the Removal Efficiency score.

Sex was not a significant factor (males, $\underline{\bar{X}}$ = .60; females, $\underline{\bar{X}}$ = .59) nor were any of the interactions.

So while picture exposure behaviors (Removal Efficiency) improved with increased age, no evidence is available to suggest that contour exposure behaviors similarly improved. Unknown, however, is whether the nonsignificant trend reflects a measure of abilities or is a function of the lack of instructions addressed to contour exposure removals. Therefore, this score will not add materially to the overall analysis.

Information Utilization Score

The Information Utilization score is defined as a ratio of number of pieces removed on the picture divided by the total number of pieces which initially covered the picture. This score is an indication of the proportion of stimulus exposed prior to being correctly identified. Better performance is indicated by a lower score suggesting a functional need for less information or, in other words, better utilization of existing information. For this score, analysis of variance again indicated significant Age and Picture factors only (see Table 1).

The mean scores for each age group in Table 2 indicate, as with the Picture Identification score, a performance plateau between ages 5 and 6 and ages 8 to 11 (see also Figure 5). Overall, the proportion of

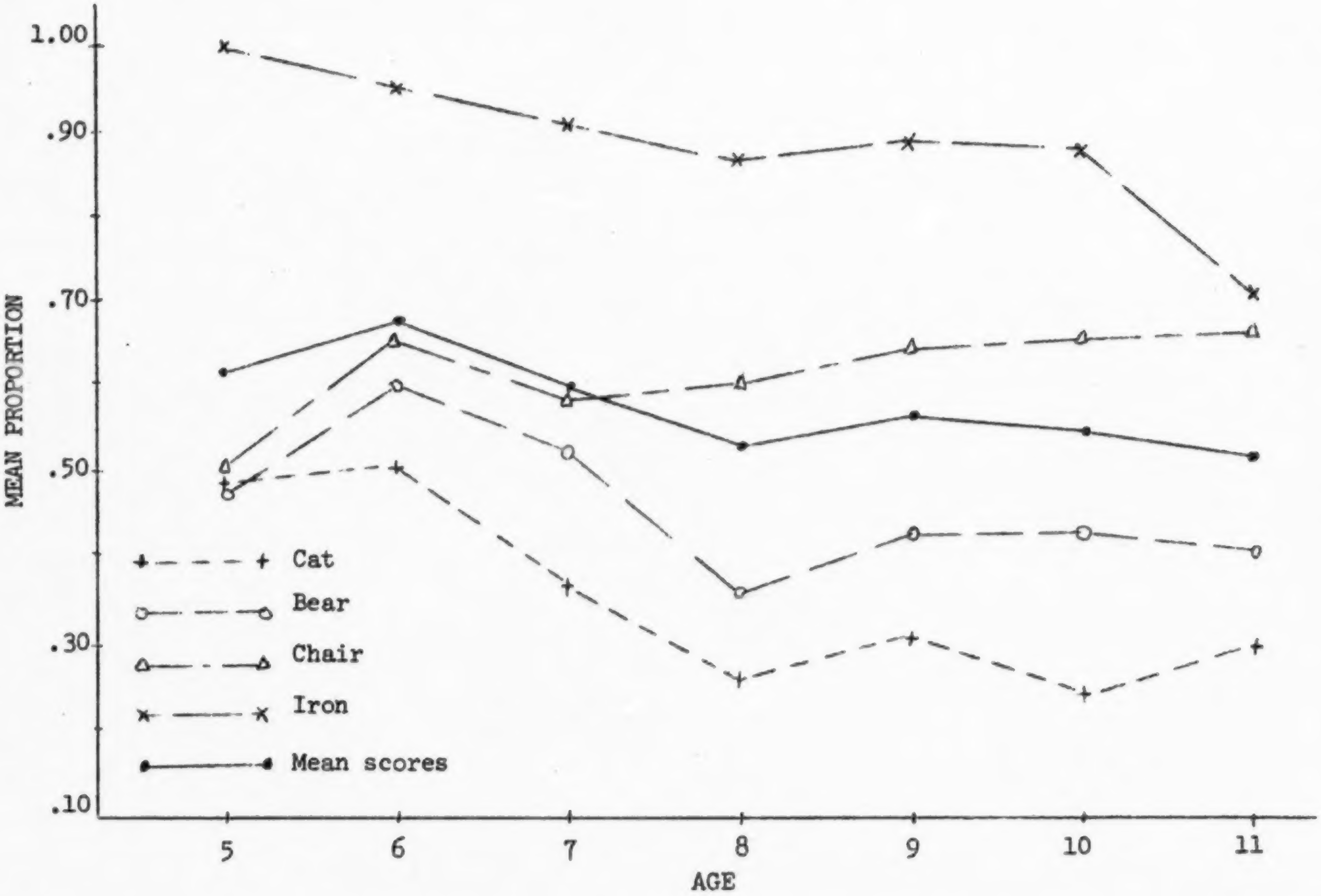


Fig. 5. Subjects' Information Utilization scores on the four stimuli used in Experiment I.

required information decreased from 68% (age 6) to 52% (age 11). However, significantly different performances between adjacent ages occurred only for the 6- and 7-year-olds ($\underline{t} = 2.04$, $\underline{df} = 84$, $\underline{p} < .05$). From 5 to 11, the general age related improvement was significant only at age 8 ($\underline{t} = 2.37$, $\underline{p} < .05$) and age 11 ($\underline{t} = 2.48$, $\underline{p} < .05$), even though performance at age 6 was significantly worse than all subsequent age groups ($\underline{t} = 2.04$, $\underline{p} < .05$; $\underline{t} = 3.94$, $\underline{p} < .001$; $\underline{t} = 2.84$, $\underline{p} < .01$; $\underline{t} = 3.23$, $\underline{p} < .01$; $\underline{t} = 4.05$, $\underline{p} < .001$). The only other significant developmental change was the improvement of age 11 subjects over age 7 subjects ($\underline{t} = 2.01$, $\underline{p} < .05$.)

The general order, as with all but the Contour Efficiency score, was again cat, bear, chair, and iron (see Table 2). With each picture covered by approximately 74% of the removal-piece matrix, cat was significantly easier than bear ($\underline{t} = 4.33$, $\underline{df} = 252$, $\underline{p} < .001$), bear was significantly easier than chair ($\underline{t} = 6.04$, $\underline{p} < .001$), which was significantly easier than iron ($\underline{t} = 10.50$, $\underline{p} < .001$).

Again, as with all scores except Verbalization Rate, interactions were not significant. Also, males ($\underline{\bar{X}} = .58$) performed only slightly better than females ($\underline{\bar{X}} = .59$).

While five scores were discussed, three (Verbalization Rate, Removal Efficiency, and Information Utilization) were of primary importance to this experiment. A comparison of these scores follows in the next section.

Discussion

Two critical questions considered were: (a) Is there evidence to suggest a differential growth rate of hypothesizing (Verbalization Rate) and strategy efficiency (Removal Efficiency) abilities in comparison to information utilization (Information Utilization score) ability; and (b) Can differentially difficult stimuli be a functional determinant of the age range where information processing impediments occur.

In an analysis of subjects' response patterns on probability learning tasks, Weir suggests that children approximately 7 to 10 years of age respond in a highly stereotyped fashion. Apparently younger (3-year-old) subjects never used these stereotyped response patterns and the older subjects (11 to 19) initially used but quickly discarded the patterns when unsuccessful. Weir initially suggested that either the stereotyped pattern users cannot generate more complex patterns or that they cannot fully utilize information available from their own responses. From his study and a review of others, Weir presents support for the latter hypothesis.

In the Cox and Fletcher study, the Weir hypothesis gains further support since the scores reflecting hypothesis generation and strategy employment (but not the information utilization score) improved monotonically with age. More specifically, performance for subjects ages 4, 6, 8, and 10 increased with age from 71 to 93% efficiency and from an 11 to 19% verbalization rate without, in either case, any age-related leveling trend. However, while subjects' picture exposure requirement (information utilization) decreased (improved from 56 to 37%) with age, a definite performance plateau occurred between ages 6 and 8. In fact, 8-year-old subjects required more picture exposure (45%) than did 6-year-old subjects (42%).

Figure 6 presents the developmental trends for the three scores of interest in this study. While a general monotonic improvement occurred for the Removal Efficiency score and the Information Utilization measure showed a definite nonmonotonic improvement, the Verbalization Rate score lacked any improvement at all thus failing to clearly support the Weir hypothesis. That is, a monotonic improvement should have occurred for both the Removal Efficiency and Verbalization Rate scores. Furthermore, existence of two performance plateaus in the Information Utilization score casts doubt on the applicability of the Weir explanation. Nowhere does Weir mention the existence or possibility of two distinct plateaus. However, it is possible that both plateaus were not a function of the same behavior.

Even so, it appears as though differential growth rates, three in fact, do exist. Removal efficiency steadily improves, information utilization sporadically improves, while hypothesizing behavior remains relatively constant. So, while the Weir explanation is apparently insufficient, differential growth rates of hypothesizing, strategy employment, and information utilization do exist. The

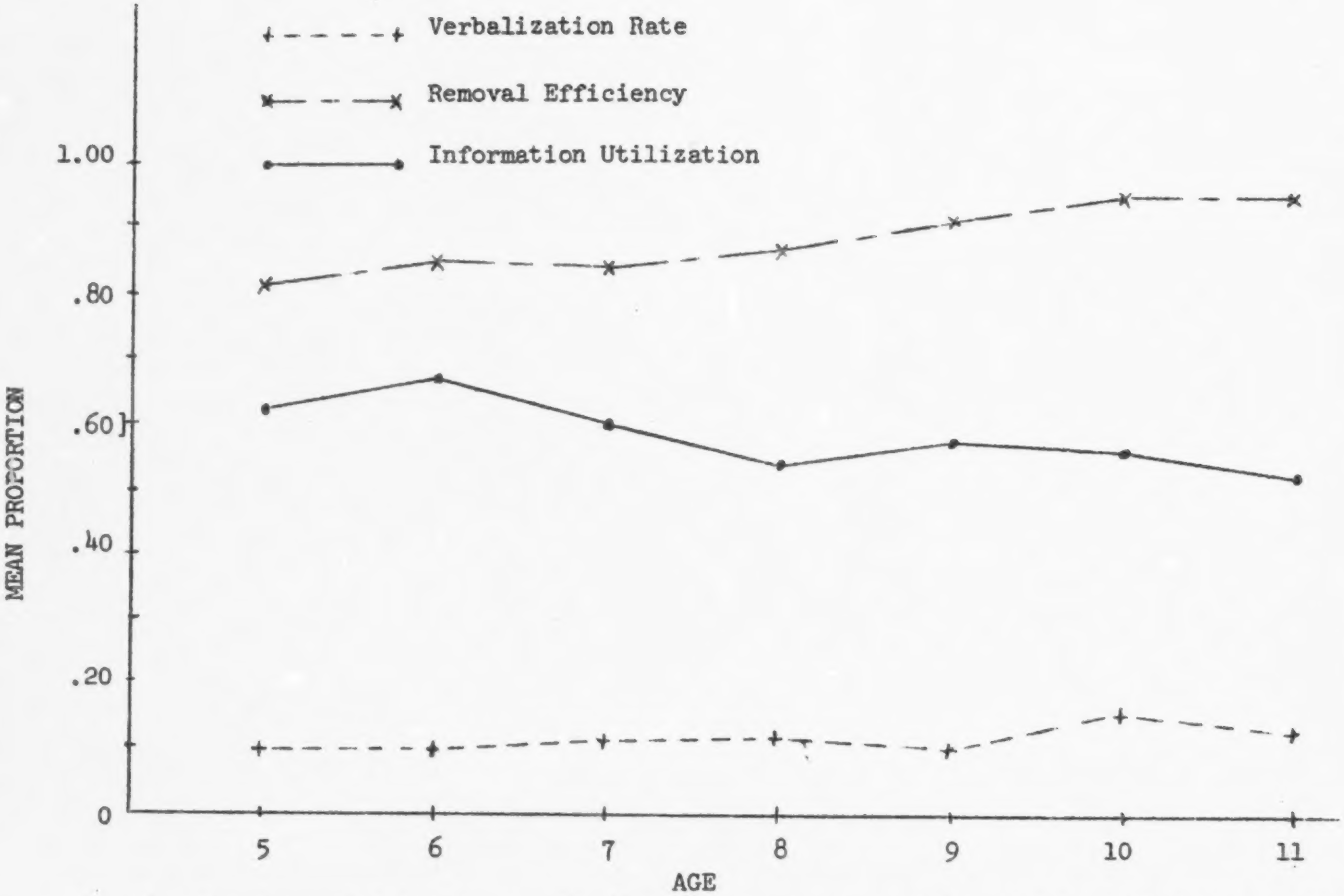


Fig. 6. Developmental trends for the three scores representative of hypothesis generation, strategy employment, and information utilization abilities in Experiment I.

existence of three distinct growth rates is counter to the Weir and Cox and Fletcher findings of two (hypothesizing and strategy employment versus information utilization) rates and suggests the need for follow-up research.

In defense of Weir, the tasks in the present experiment were entirely unlike his and no analogy was made with the pattern utilization behaviors which he examined. In fact, only a complex computer scoring process appears capable of compiling behavior-pattern-supportative evidence in the present tasks.

A further explication and verification of the Weir hypothesis follows in answer to the question concerning age range variability. Possibly resulting from an insufficient memory for long sequences, difficult tasks cause subjects, according to Weir, to exceed their information processing capability developmentally earlier than do the easier tasks. Difficulty was operationally established in accordance with the number of possible choices available in the task environment. In the Cox and Fletcher study, differentially difficult pictures (on six measures) failed to elicit any age-related plateau shifts.

In the present study there is also no indication of a plateau shift, or an Age by Picture interaction (see Figure 5). The first developmentally occurring plateau consistently appears between ages 5 and 6 for all but the iron stimulus where it does not occur at all. Moreover, since performance on the iron picture for 5-year-olds is at the maximum rate, one cannot argue that the plateau for this picture occurred developmentally earlier (i.e., before age 5). The second plateau, between ages 8 and 11, appeared beginning at age 8 for all except the chair stimulus. By age 11, performance improved again on the bear and iron pictures but continued in a plateau stage on the chair picture. Were it not for the unexpected performance for 10- and 11-year-old subjects on the cat stimulus, a possible hypothesis from the above data would relate to plateau duration rather than initial plateau occurrence. This hypothesis, which suggests that picture difficulty determines the span rather than the onset of the age-related plateau, is without support also.

In summary, only partial support was obtained for hypothesizing a differential growth of the hypothesizing and strategy employment abilities versus the information processing ability. In fact, while the plateau shift concept remains totally unsupported, the rate of growth is separate and distinct for each of the three abilities. Whether this latter finding represents a more precise indication than what has previously been reported or whether it requires a totally new interpretation is an open and apparently researchable question. Certainly, the differences in ability growth rates among this, the Weir, and the Cox and Fletcher study demand further investigation.

CHAPTER III

EXPERIMENT II

Statement of Problem

This study tested the appropriateness of a two-stage scientific reasoning model on conceptually based stimuli. As with the Periodic Table invention mentioned earlier, scientific reasoning involves the two stages of induction and deduction. Induction, or the hypothesis generation stage, involves inventing a solution (pattern, model, law, or scheme) from only partial information, and deduction, or the hypothesis testing stage, involves systematically testing the hypothesis or hypotheses by predicting new information or results.

Several studies and models of cognition have either alluded to or specifically hypothesized the existence of inductive and deductive reasoning stages. D. M. Johnson (1961) labeled the two stages of induction and deduction, respectively, preparation and solution, but later (Johnson & Jennings, 1963) expanded the deduction stage into production and judgment components. Simon and Sumner (1968) propose that performance on a letter series test involves: (a) inducting an appropriate pattern, and (b) generating the appropriate successive symbols; and Fletcher (1969) proposes transformation and generation stages (among others) of information processing. In these instances, the processes appear analagous to the inductive and deductive stages proposed by Cox (1972). For him, induction involves information encoding and generation activities while deduction involves testing hypotheses and extending the results to additional situations.

After reviewing related studies, Cox cited the need for research which functionally isolates inductive and deductive processes. However, the existing research methodology is generally unable to separate these processes which perhaps function differentially in both laboratory and real-life situations. An exception is the demonstration (Duncan, 1964) of performance differences that occur between those subjects who are allowed to both "induce" (hypothesize) and deduce (test) and those subjects who are allowed to induce only. That is, subjects were more successful when free to select (induction-deduction) number-letter pairs for discovering their relationship than when restricted either partially or entirely (induction) in the selection process.

Certainly, the need exists to further investigate inductive and deductive processes. However, existence of additional clarifying research is practically nonexistent. For example, a number of studies (i.e., Gollin, 1960, 1961, 1962, 1965; Messick & Hills, 1960; Mooney, 1957a, 1957b, 1957c; Smock, 1955, 1957; Westcott, 1968), while utilizing fragmented evidence (induction), do not allow subjects to determine their own acquisition sequence, thus restrict the full utilization of deductive processes.

One purpose of this study, then, was to investigate the relationship between these two reasoning processes. The nature of the experiment was as follows: each subject in a master experimental group was allowed to follow a self-initiated stimulus identification sequence which a slaved control group partner (yoked-control) was required to follow while attempting to predict a binary event in a matrix of cells.

A second purpose of this experiment was to examine scientific reasoning performances on more conceptually based stimuli than those used in Experiment I. Cox (pp. 54-55) specifically notes that the nature of scientific reasoning generally emphasizes spatial and symbolic rather than temporal and pictorial stimuli. Even while evidence accumulates over time, the data, generally symbolic in nature, are analyzed in spatial rather than temporal schemes. Furthermore, symbolic material elicits the generational processes of interest in contrast to the memory processes elicited by pictorial stimuli.

Even so, the majority of research (which can be interpreted as measuring inductive reasoning) utilizes familiar, perceptual figures rather than unfamiliar, conceptually oriented stimuli (e.g., Gollin, 1960, 1961, 1962, 1965; Westcott, 1968). Also, those models (i.e., Simon & Sumner, 1968; Klahr & Wallace, 1970) and related studies (i.e., Azuma & Cronbach, 1966; Beach, 1964; Simon & Kotovsky, 1963) which utilize conceptually based patterns primarily emphasize temporal rather than spatial configurations. To follow the research implications suggested by Cox, this experiment investigated inductive and deductive performances with more appropriate symbolic, symmetrical patterns.

Additionally, this experiment extended the age range investigated to include subjects 9-to-14-years-old. It is during this approximate age period in which Piaget (Inhelder & Piaget, 1958) suggests that children develop the ability to formulate and test hypotheses without actually manipulating concrete objects. It is also during this time that children become able to envision reality as a subset of a larger set of possibilities. Hence, the target subjects appear capable of the task requirements.

Method

Subjects

Subjects were again selected from classes in the Florida State University Laboratory School. Selection of subjects was random within the constraint that Experiment I subjects were not used (two violations of this restriction occurred). Also, to meet the master and slaved requirements, like-sex subjects in each age group were paired, after selection, to achieve minimum IQ score differences (California Mental Maturity Test scores. Form S, 1963, taken from school records).

One hundred twenty subjects, 10 male and 10 female in each of the 9-, 10-, 11-, 12-, 13-, and 14-year-old age groups, completed the experimental tasks. Racial composition of the age groups was 1 black and 19 whites in the 10- and 12-year age groups; 3 blacks and 17 whites in the 9-, 11-, and 13-year age groups; and 6 blacks and 14 whites in the 14-year age group. Mean age and range in months for each age group was as follows: 9-year-olds ($\overline{X}$ = 107.0, range 101-114); 10-year-olds ($\overline{X}$ = 121.4, range 114-126); 11-year-olds ($\overline{X}$ = 130.9, range 127-138); 12-year-olds ($\overline{X}$ = 145.3, range 138-150); 13-year-olds ($\overline{X}$ = 155.1, range 150-162); and 14-year-olds ($\overline{X}$ = 170.9, range 163-178). Mean, range and median difference in paired IQ scores for each sex by age group were: 9-year-olds (males--$\overline{X}$ = 121.2, range 109-135, median 3.0; females--$\overline{X}$ = 117.6, range 92 -142, median 9.0); 10-year-olds (males--$\overline{X}$ = 112.1, range 99-127, median 2.0; females--$\overline{X}$ = 119.1, range 101-130, median 3.3); 11-year-olds (males--$\overline{X}$ = 112.6, range 93-122, median 1.3; females--$\overline{X}$ = 109.6, range 92-128, median 2.0); 12-year-olds (males--$\overline{X}$ = 110.1, range 88-138, median 3.0; females--$\overline{X}$ = 114.0, range 95-124, median 5.0); 13-year-olds (males--$\overline{X}$ = 110.0, range 94-139, median 7.0; females--$\overline{X}$ = 111.5 range 96-123, median 3.3); and 14-year-olds (males--$\overline{X}$ = 114.7, range 94-129, median 3.0; females--$\overline{X}$ = 104.3, range 83-121, median 4.3).

Apparatus and Stimulus

Test apparatus (see Figure 7) was identical to that used in Experiment I except for a difference in instrument size and number of

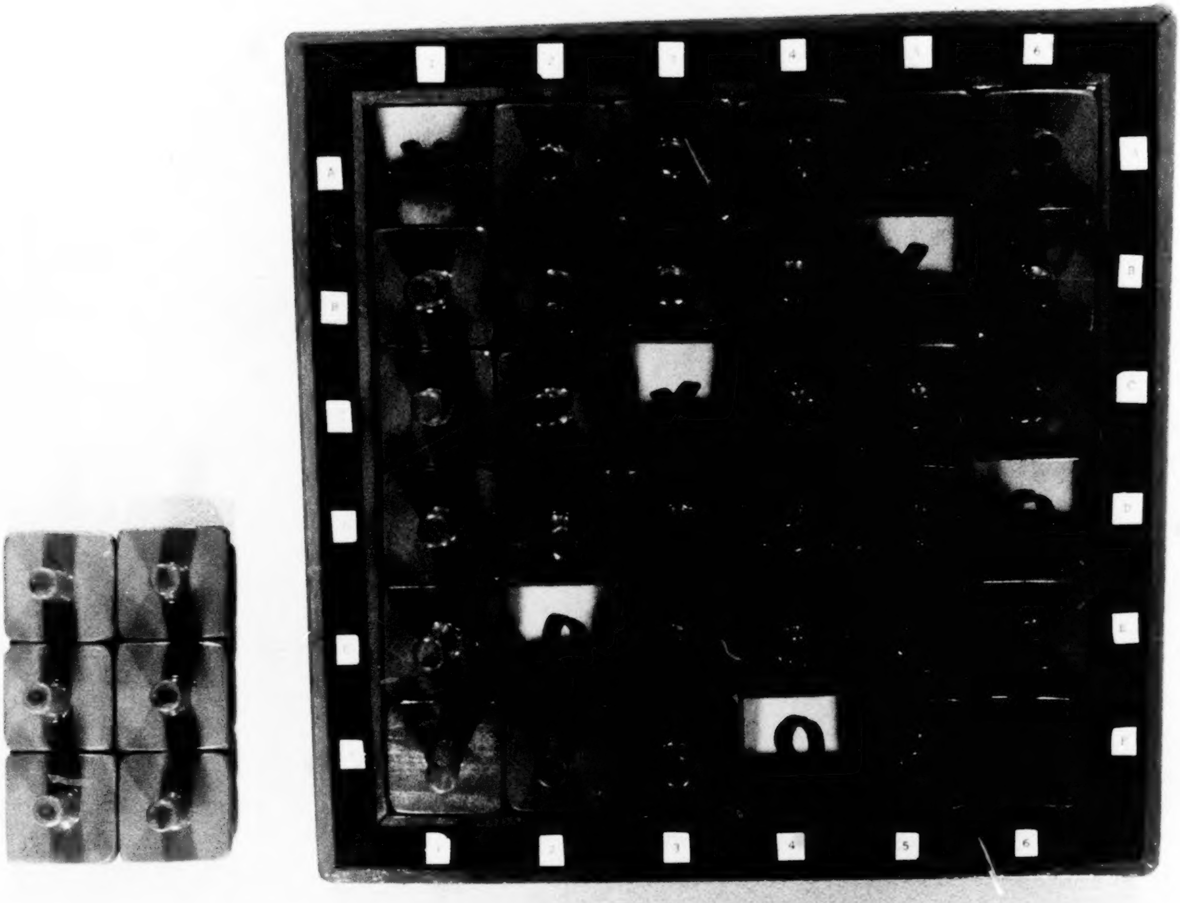


Fig. 7. Test instrument used in Experiment II.

matrix pieces. This time the device (10 in. width x 10 in. length x 1 in. depth) was covered by a 6 x 6 matrix of 36 removable wooden pieces (1-3/8 in. x 1-3/8 in. x 1/4 in.).

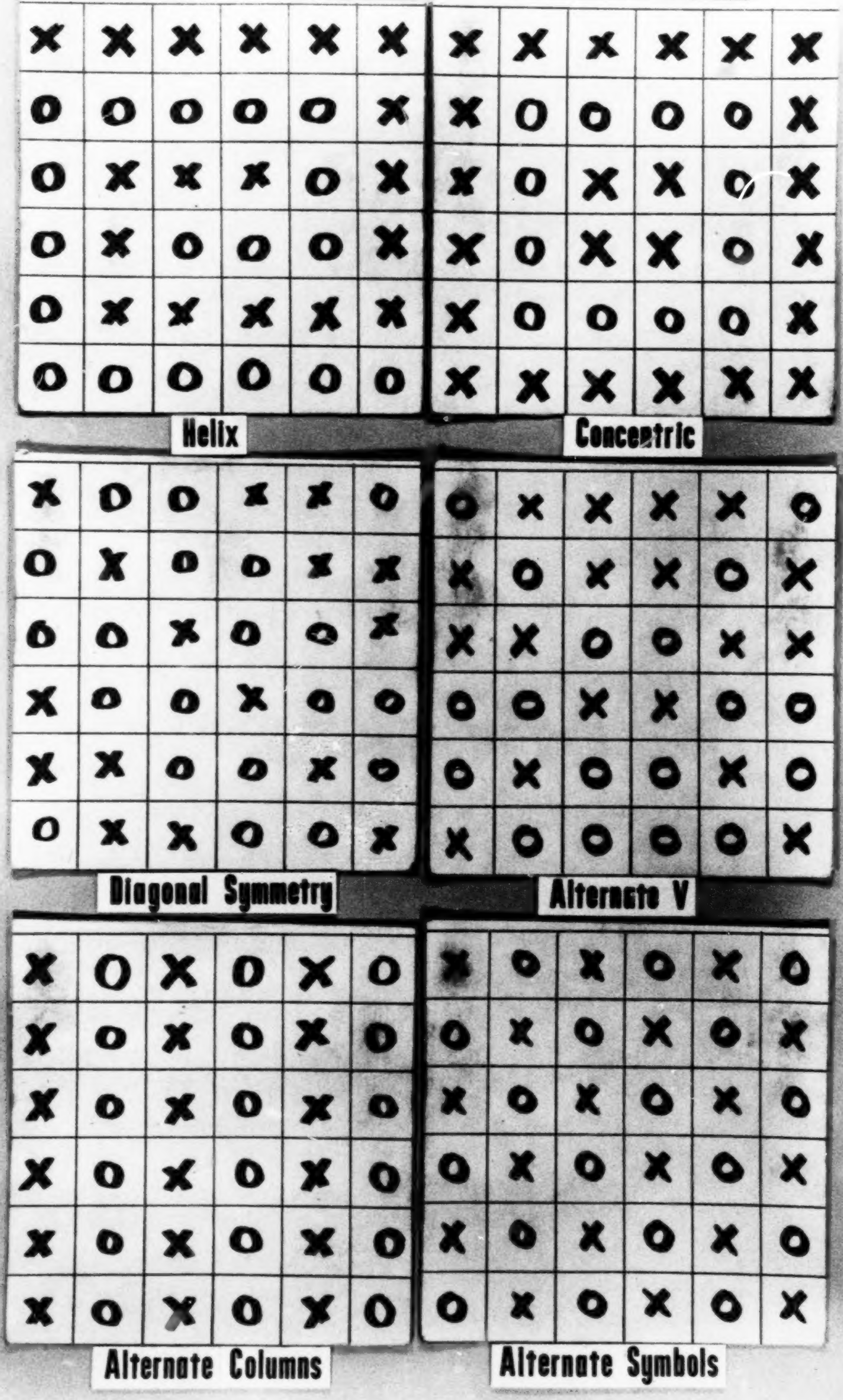
Stimuli used in the test apparatus were six symmetrical patterns of binary information (see Figure 8). A stimulus sheet consisted of 36 cells, each containing either an X or a 0, and all of which comprised a given pattern. Results from a pilot study suggested that the following stimuli were appropriate for the target subjects: Alternate Symbols (AS), Alternate Columns (AC), Concentric (C), Alternate V (AV), Diagonal Symmetry (DS), and Helix (H). An additional criterion for selection was that, summing across all stimuli, the total number of X's and 0's must equal.

Procedure

Preexperimental conditions (e.g., test rooms, experimenter-subject interaction) were similar to those in Experiment I. Again, Ss had no previous knowledge of stimulus identities. Prior to admitting S, stimuli were randomly ordered and placed under the plexiglass. An experimental, or master, S was admitted first and followed, when finished, by his slaved or yoked-control S.

Master Subject. Prior to actually administering the tasks, S was asked if he knew what patterns were being used. One S appeared to possess task preknowledge (substantiated by task performances) and was

Fig. 8. Six pattern stimuli used in Experiment II.



X	X	X	X	X	X
O	O	O	O	O	X
O	X	X	X	O	X
O	X	O	O	O	X
O	X	X	X	X	X
O	O	O	O	O	O

Helix

X	X	X	X	X	X
X	O	O	O	O	X
X	O	X	X	O	X
X	O	X	X	O	X
X	O	O	O	O	X
X	X	X	X	X	X

Concentric

X	O	O	X	X	O
O	X	O	O	X	X
O	O	X	O	O	X
X	O	O	X	O	O
X	X	O	O	X	O
O	X	X	O	O	X

Diagonal Symmetry

O	X	X	X	X	O
X	O	X	X	O	X
X	X	O	O	X	X
O	O	X	X	O	O
O	X	O	O	X	O
X	O	O	O	O	X

Alternate V

X	O	X	O	X	O
X	O	X	O	X	O
X	O	X	O	X	O
X	O	X	O	X	O
X	O	X	O	X	O
X	O	X	O	X	O

Alternate Columns

X	O	X	O	X	O
O	X	O	X	O	X
X	O	X	O	X	O
O	X	O	X	O	X
X	O	X	O	X	O
O	X	O	X	O	X

Alternate Symbols

subsequently dismissed and replaced by an appropriate substitute.

The following verbal instructions were then given to the master S:

> Underneath all these pieces is a pattern of X's and O's. For example, it will be similar to these patterns (show five similar but not identical patterns) but it won't be any of these patterns. You have to tell me what the entire pattern is by removing the pieces one at a time. However, before picking up each piece you must tell me whether it covers an X or O. Remember, you want to name the entire pattern as soon as you can. Okay, begin.

Throughout the procedure, Ss were asked but not required to identify the entire pattern on approximately every fourth instrumental response (piece removal). The individually determined removal sequence, all cell identifications, hypothesized pattern identities, and performance times were recorded on a 36 cell, matrix-matched protocol sheet. Each S was required to remove all 36 pieces (one by one) regardless of identification correctness.

After complete stimulus exposure, S and E's discussed the pattern identity. The pieces were then replaced on the instrument, the stimulus pattern removed, and the entire procedure repeated for each remaining pattern. Upon task completion, the S was dismissed after being cautioned not to discuss the experiment with other students. Procedures for admitting the paired, slave S were then initiated.

Slaved subject. Each slaved subject received stimuli in an order identical to the master subject presentation. Other procedures remained the same except for the following changes. Slaved Ss received the original plus these additional directions prior to beginning:

> You must remove the pieces as I tell you. Okay, start by removing piece number (e.g., A1).

Thus each slave received the same order of patterns and the same square-removal sequence within each pattern as did his master. Moreover, in an attempt to equate the time taken for both Ss, E paced the slave so that he would complete the square-removal sequence in approximately the time taken by the master. As before, the slaved S was required to name each cell (X or O) prior to piece removal and asked but not required to hypothesize the entire pattern identity as he removed every fourth piece.

Each master and slaved subject received, in a 30 to 50 minute session, the experimental task, and questions and advice concerning advance knowledge of the experiment. The randomization schedule for testing master-slaved Ss was generally followed with only a few minor deviations occurring because of class schedule conflicts.

Dependent Measures

The following scores were computed and analyzed:

1. Cell Prediction score--defined as the number of correctly predicted cells divided by the total number of cells (36).

2. Pattern Hypothesis Onset score--defined as the proportion of pieces removed when the first overall pattern hypothesis occurred.

3. Pattern Hypothesis Accuracy score--defined as the proportion

of pieces removed to total pieces when the first correct overall pattern hypothesis occurred.

4. Pattern Hypothesis Quantity score--defined as the number of different verbalized overall pattern hypotheses. And,

5. Time score--defined as the time (in seconds) from first to last (36) piece removed.

Design and Analysis

A 6 x 2 x 2 x 6 (Age by Sex by Experimental Condition by Stimulus) design was used. Five pairs of males and five pairs of females (10 pairs) within each age group received two experimental conditions and six stimulus patterns as repeated measures.

A 6 x 2 x 2 x 6 analysis of variance was computed for each dependent measure. All subsequent _t_ tests were two-tailed and utilized a pooled error term from the analysis of variance. A positive bias correction was applied to all tests on repeated measure sources (Greenhouse & Geisser, 1959). The alpha level for statistical significance was .05.

Results

Analysis of variance _F_ ratios are reported in Table 3. Age, Experimental Condition (master-slave), and Stimulus factors were all significant in four (though not always conjointly) of the five measures. A detailed discussion of each dependent measure follows. The first

TABLE 3

Summary of F Values (ANOVA) for Experiment II

Source	df	Dependent measures				
		1	2	3	4	5
Between Pairs	59					
Age (A)	5	2.74*	4.20**	6.30***	3.51**	1.00
Sex (G)	1	< 1.00	2.35	< 1.00	< 1.00	< 1.00
A x G	5	< 1.00	< 1.00	< 1.00	1.54	< 1.00
Pairs (Ps) within AG	48					
Within Pairs	660					
Stimuli (S)	5	222.33***	88.33***	330.25***	24.41***	42.50***
S x A	25	1.17	1.59	1.60	2.08	1.31
S x G	5	1.31	< 1.00	< 1.00	< 1.00	1.18
S x A x G	25	< 1.00	< 1.00	< 1.00	1.29	< 1.00
S x Ps within AG	240					
Condition (C)	1	< 1.00	18.59***	4.35*	7.23**	8.38**
C x A	5	1.52	2.09	1.30	2.88*	< 1.00
C x G	1	1.48	1.36	< 1.00	3.56	< 1.00
C x A x G	5	1.21	< 1.00	< 1.00	1.43	2.57*
C x Ps within AG	48					
C x S	5	< 1.00	<<1.00	2.59	< 1.00	4.03
C x S x A	25	< 1.00	< 1.00	< 1.00	< 1.00	1.37
C x S x G	5	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00
C x S x A x G	25	< 1.00	1.13	< 1.00	< 1.00	<1.00
C x S x Ps within AG	240					

1. Cell Prediction score
2. Pattern Hypothesis Onset score
3. Pattern Hypothesis Accuracy score
4. Pattern Hypothesis Quantity score
5. Time score

* $p < .05$
** $p < .01$
*** $p < .001$

score indicates individual cell prediction behaviors, the next three scores indicate whole pattern hypothesis behaviors, and the last score indicates task performance times.

Cell Prediction Score

Cell Prediction is a ratio of: number of correctly predicted cells divided by the total number of cells (36). Supposedly, subjects were deducing individual cell identities from some induced pattern hypothesis. This measure reflects explicitly stated, deductively derived consequences of induced pattern hypotheses. Analysis of variance indicated significant Age and Stimulus factors (see Table 3).

As depicted in Table 4, cell predictions improved from 75% at age 9 to 79% at age 14. The improvement was nonmonotonic, however, with performance plateaus occurring between ages 9 and 10 and ages 13 and 14. Developmentally, scores for adjacent age groups did not significantly differ ($\underline{p} > .05$).

With regard to the Experimental Condition, master ($\underline{\bar{X}} = .76$) and slaved ($\underline{\bar{X}} = .76$) subjects performed identically. Furthermore, master and slaved subject cell predictions improved similarly with increased age.

The mean scores for patterns, as indicated in Table 5, ranked, from most to least cells identified, as follows: AS, AC, C, H, DS, and AV. Except for the nonsignificant ($p > .05$) differences between mean

TABLE 4

Age Means for each Dependent Measure in Experiment II

Scores	Ages					
	9	10	11	12	13	14
1. Cell Prediction	.75	.74	.75	.77	.79	.79
2. Pattern Hypothesis Onset	.64	.62	.61	.53	.46	.50
3. Pattern Hypothesis Accuracy	.80	.74	.73	.68	.65	.67
4. Pattern Hypothesis Quantity	.98	.93	.96	1.12	1.31	1.23
5. Time	168.22	204.33	167.29	187.60	179.58	141.03

TABLE 5

Stimulus Means for each Dependent Measure in Experiment II

Scores	Stimuli					
	Alternate Symbols	Alternate Columns	Concentric	Alternate V	Diagonal Symmetry	Helix
1. Cell Prediction	.92	.90	.81	.62	.63	.70
2. Pattern Hypothesis Onset	.31	.33	.50	.74	.76	.72
3. Pattern Hypothesis Accuracy	.34	.38	.70	.95	.95	.96
4. Pattern Hypothesis Quantity	1.16	1.22	1.56	.79	.78	1.01
5. Time	127.03	122.03	152.48	229.47	227.08	189.97

scores for AS and AC, and DS and AV, the means for all other patterns differed significantly at the .001 level. As a result, AS and C had the most, and DS and AV the least number of cells predicted, with C and H located between the extremes but not as one medium difficulty class.

No other factors nor interactions were significant. Females ($\underline{\bar{X}}$ = .77) performed only slightly better than males ($\underline{\bar{X}}$ = .76).

The general equivalence of performances for subjects in the two experimental conditions was unexpected. This similarity in master-slaved subject performances across all ages indicates that all subjects were predicting individual cells equally well regardless of piece removal control.

Interpretation of these results will be presented in the Discussion section. The next three scores indicate overall pattern inducing behaviors.

Pattern Hypothesis Onset Score

Pattern Hypothesis Onset score is defined as the ratio of: number of pieces removed when the first overall pattern hypothesis was verbalized divided by the total number of instrument pieces (36). The first hypothesis (correct or incorrect) occurred as either a subject-offered or experimenter-probed verbalization. Indicating the proportion of pattern exposed at the first hypothesis, the score reflects subjects' willingness to make total pattern inductions on the basis of partial information. Lower scores indicate earlier verbalized inductions than do higher scores and, therefore, a greater propensity to verbally report inductions on the basis of less information. Analysis of variance F ratios, as depicted in Table 3, were significant for the Age, Experimental Condition, and Stimulus factors.

Performance, as with the previous measure, improved nonmonotonically between ages 9 and 14. Even with the general improvement, however, mean scores for adjacent age groups were again not significantly different ($p > .05$). Moreover, an apparent performance plateau occurred between ages 13 and 14. In general, subjects required from 64% to 46% pattern exposure before offering an initial hypothesis.

The significant Experimental Condition factor indicated that slaved subjects verbalized their first hypothesis with less exposed information than did master subjects (see Table 6). Since removal sequences were identical for both master and slaved subjects, exposed information was identical for both at any instance. Master subjects consistently required more pattern exposure than did slaved subjects from ages 9 through 12. Only at ages 13 and 14 did the two experimental condition groups perform somewhat equally.

The rank order of stimuli, from least to most exposure before the first hypothesis, was AS, AC, C, A, AV, and DS. Patterns AS and AC formed the easiest class; H, AV, and DS the most difficult class; with C at a medium difficulty level. Significant differences occurred between

TABLE 6

Experimental Condition Means at each Age Group for the Dependent Measures in Experiment II

Age	Scores				
	Cell Prediction	Pattern Hypothesis Onset	Pattern Hypothesis Accuracy	Pattern Hypothesis Quantity	Time
			Master		
9	.74	.66	.80	.93	167.43
10	.75	.69	.74	.75	199.92
11	.73	.67	.77	.93	162.15
12	.76	.63	.72	.92	188.45
13	.78	.47	.68	1.37	176.28
14	.79	.51	.66	1.22	137.55
$\bar{X}$	.76	.60	.73	1.02	171.96
			Slaved		
9	.76	.63	.79	1.02	169.00
10	.73	.56	.74	1.10	208.73
11	.76	.55	.69	.98	172.43
12	.77	.44	.65	1.32	186.75
13	.79	.45	.62	1.25	182.88
14	.78	.49	.68	1.23	144.52
$\bar{X}$	.76	.52	.70	1.15	177.39

adjacent mean scores AC and C (t = 5.57, df = 240, p < .001) and between C and H (t = 6.83, p < .001).

All other factors and interactions were not significant. Males ($\bar{X}$ = .54) performed better than females ($\bar{X}$ = .58) but not significantly so.

Those subjects (master) responsible for their deductively derived piece removal behaviors required the most pattern exposure before hypothesizing the pattern identity. Even while the pattern exposure requirement improved with increased age, the master-slaved subject performance difference generally remained constant.

The following score also concerns overall-pattern hypothesizing behaviors. It indicates the proportion of pattern exposed when the first correct whole pattern hypothesis occurred.

Pattern Hypothesis Accuracy Score

This score is defined as a ratio of: number of pieces removed when the correct overall pattern hypothesis first occurred divided by the total number of removable pieces (36). The Pattern Hypothesis Accuracy score is a general indicator of the proportion of pattern exposure required prior to correctly inducing the pattern. Lower ratio scores indicate better pattern induction performance. The Table 3 summary of analysis of variance indicates significant Age, Experimental Condition, and Stimulus factors.

As with all previous measures, the means in Table 4 show a general but nonmonotonic improvement between ages 9 and 14. Nowhere were there significant differences between adjacent age means ($\underline{p} > .05$). As with the Cell Prediction and Pattern Hypothesis Onset scores, an apparent performance plateau existed between ages 13 and 14. Generally, subjects required 80% to 65% pattern exposure for correct identification.

A second factor of interest was Experimental Condition. The mean score (see Table 6) for the slaved subjects was significantly better (lower ratio) than for the master subjects. In general, master subjects required more stimulus exposure than did the slaved subjects for correct overall pattern inductions just as they did to verbalize their first overall pattern hypothesis.

Stimulus mean scores (see Table 5), ranked from least to most exposure, were AS, AC, C, with AV, DS, and H tied for the last three places. Adjacently ordered stimuli not significant were AS and AC, and the tied three. Stimuli AC and C differed significantly ($\underline{t} = 14.22$, $\underline{df} = 240$) at the .001 level as did stimulus C with the tied three ($\underline{t} = 11.06$; $\underline{t} = 10.99$; $\underline{t} = 11.54$). Similar to the Pattern Hypothesis Onset score, patterns AS and AC were rated as an easy class; C as a medium difficulty class; and AN, DS, and H as the most difficult class.

No other factors nor interactions were significant. For this score, as with the Cell Prediction score, males and females performed identically ($\underline{\bar{X}} = .71$).

With the age related improvement, master-slaved scores were almost identical at ages 9, 10, and 14. However, master subjects clearly required more pattern exposure than did slaved subjects at all remaining ages. Thus, it appears as though requiring subjects to expose patterns, supposedly from deductive predictions, actually deters their ability, relatively speaking, to correctly induce the pattern or even attempt a first hypothesis.

Another measure of overall-pattern induction behaviors follows next. This measure concerns the number of pattern hypotheses offered by subjects.

Pattern Hypothesis Quantity Score

This score is defined as the number of different whole-pattern hypotheses verbalized up to and including the first correct hypothesis. The score is interpreted as a measure of subjects' inductive productivity. Supposedly, these pattern hypotheses formed the bases from which the master (but not the slaved) subject removed additional pieces. Analysis of variance (Table 3) indicated significant Age, Experimental Condition, and Stimulus factors, and an Age by Experimental Condition interaction.

Discussion of the significant main effects of Age and significant Experimental Condition factors is deferred in favor of the Age by Experimental Condition interaction. As is evident in Table 4, the number of verbal hypotheses offered generally increased from age 9 to age 14 and, on the average, slaved subjects offered significantly more pattern hypotheses than did the master subjects (see Table 6). However, from Figure 9 it is obvious that the slaved subject superiority was restricted to ages 9 through 12.

Pattern mean scores (see Table 5) indicated a change in grouping from all previous scores. Ranked in descending order from most to least hypothesized, the patterns were C, AC, AS, H, AV, and DS. Patterns C and AC ($\underline{t} = 4.05$, $\underline{df} = 240$, $\underline{p} < .001$), and patterns H and AV ($\underline{t} = 2.57$, $\underline{p} < .05$) were the only significantly different adjacent stimuli. Thus C was associated with the most hypotheses; AC, AS, and H were at a medium level; and AV and DS were associated with the fewest hypotheses.

No other factors nor interactions were significant, although males ($\underline{\bar{X}} = 1.11$) did generate more hypotheses than did females ($\underline{\bar{X}} = 1.06$).

As with the Pattern Hypothesis Onset and Pattern Hypothesis Accuracy scores, the significant main effects were Age, Experimental Condition, and Stimuli. The Age by Experimental Condition interaction was significant for this measure only. For all the Pattern Hypothesis scores, slaved subjects performed better than master subjects but on the Cell Prediction score master-slaved subjects performances were generally similar at all ages.

Prior to a further discussion of these scores, a fifth measure

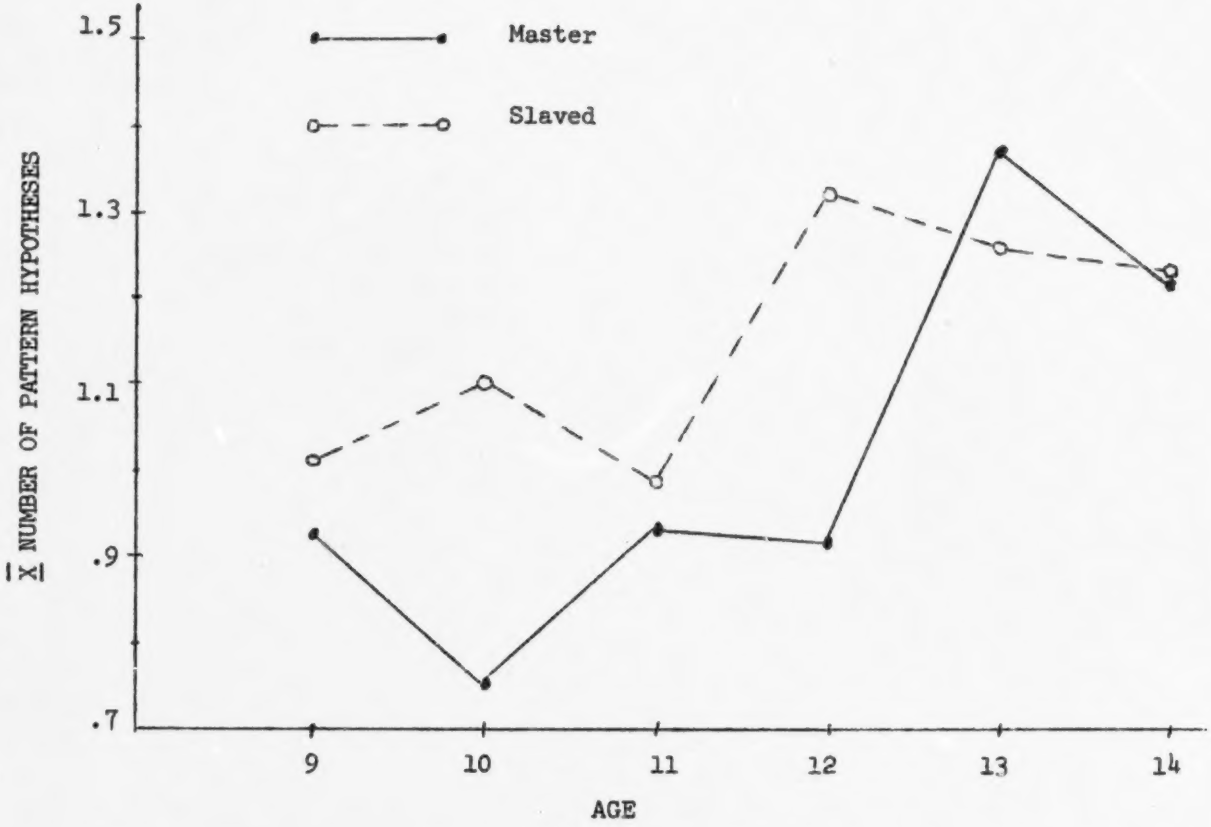


Fig. 9. Pattern Hypothesis Quantity scores for master and slaved subjects in Experiment II.

is analyzed next. This next measure or score concerns task performance times.

Time Score

Time score is defined as the time (in seconds) from first to last piece removed. Since all subjects were required to complete each pattern task, i.e., to remove all 36 pieces, this score was computed independently of the onset, quantity, and accuracy of either cell predictions or pattern hypotheses. For the same reason, this score has a constant baseline thus indicating the piece removal rate--lower scores indicate faster piece removal behaviors. A faster removal rate, in turn, reflects impulsive behaviors while slower rates suggest reflective behaviors. Analysis of variance (see Table 3) indicates significant Stimulus and Experimental Condition factors and an Age by Sex by Experimental Condition interaction.

While the master and slaved subject overall mean performances (see Table 6) were significantly different, a discussion of these means must be qualified by the significant Age by Sex by Experimental Condition interaction. Even so, the discussion is simplified somewhat by the nature of the task requirements. As discussed in the procedures section, each slaved subject was paced, as closely as possible, to the m master subjects rate of removal. So while the slaved subjects took, on the average, a significant 5.43 seconds longer, this difference represents a confounding of experimenter technique and subject behaviors and is consequently uninterpretable. Therefore, the following discussion concerning the Age by Sex interaction represents only the master but not the slaved subject performances.

Performance curves representing male and female master subjects in each age group are shown in Figure 10. Male masters took longer than female masters to complete the tasks for all ages except 10 and 11.

Stimulus mean scores ranked from least to most times are as follows: AC, AS, C, H, DS, and AV. Significantly different adjacent patterns were AS and C ($\underline{t} = 2.44$, $\underline{df} = 240$, $\underline{p} < .05$), C and H ($\underline{t} = 3.60$, $\underline{p} < .001$), and H and DS ($\underline{t} = 3.56$, $\underline{p} < .001$). Thus, as with the Cell Prediction score, AC and AS stimuli were easy and DS and AV were difficult, while C and H were not of a singular, medium difficulty class.

No other factors nor interactions were significant. As shown in Figure 10, only at age 14 was there an age-related though nonsignificant overall decrease in performance time. The three-way Age by Sex by Experimental Condition interaction was significant for this score only.

In summary, the results indicate that only for the induction and not the deduction performance do master and slaved subjects differ. Apparently, the process of induction is related to whether or not one is able to actively test his deductions. An overall discussion of these measures follows next.

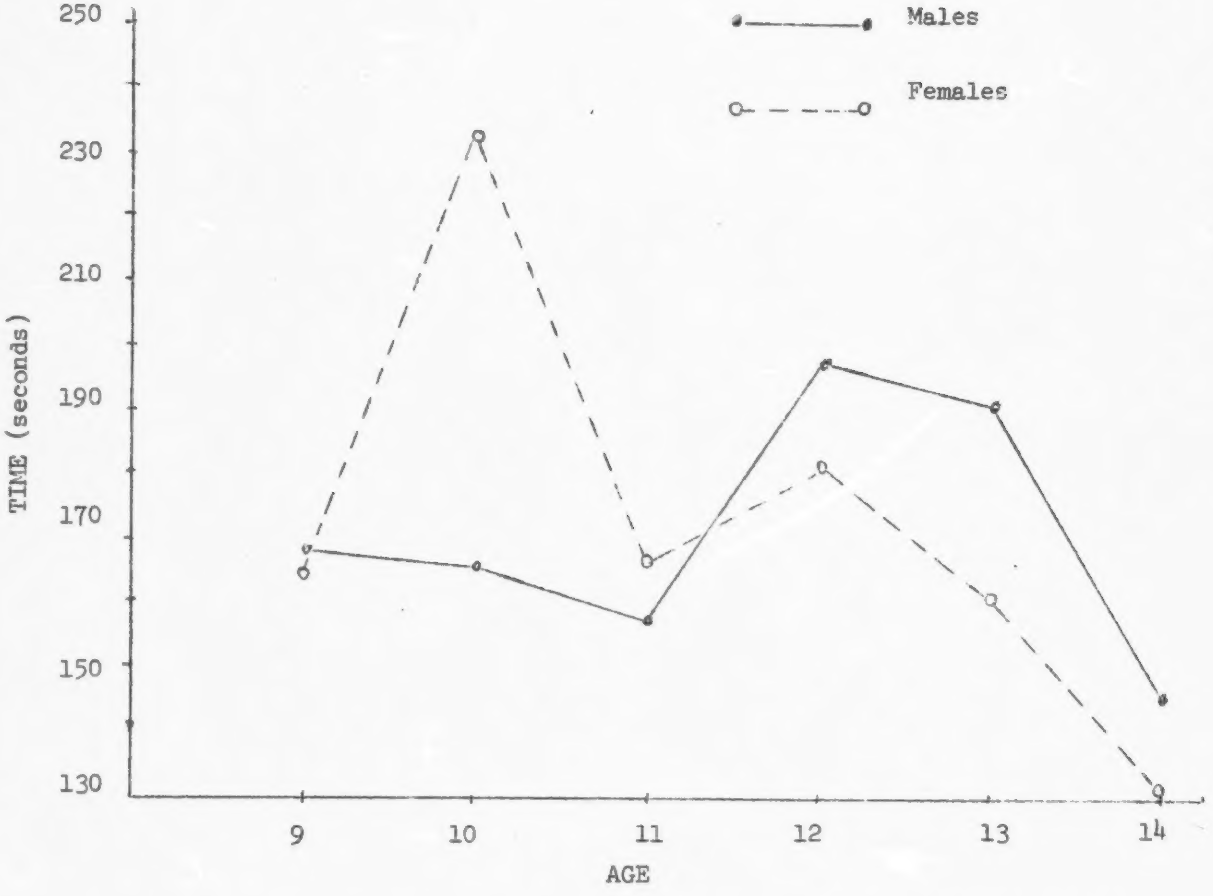


Fig. 10. Time to task completion for master subjects in Experiment II.

Discussion

The finding of primary interest was the generally equivalent master-slaved cell prediction behavior but "better" whole pattern induction behavior for slaved subjects. Basically, slaved and master subjects differed in the way their deductions were tested.

An examination of the behaviors involved in task performance suggests two different sequences of hypothetical processes. For the master subject, piece removals expose, at any given instance, a certain proportion of the pattern. On the basis of the information exposed, the master subject induces a pattern which is at least consistent with that available information. Then, knowing that another cell must be predicted, the master subject deductively predicts, from his pattern, the identity of a cell of his choice. If the cell identity confirms the pattern, the process is again repeated starting from the cell production step. If the evidence is disconfirming, then the process starts over at the pattern induction step.

For the slaved subject, the processes were the same but their order of occurrence was not. Again, on the basis of the same exposed information, a pattern is induced. The slaved subject is then directed to a specific cell (not of his own choosing) which he must then predict. If the prediction is correct, the process is repeated without re-inducing a new pattern. If the cell was incorrectly predicted, the process repeats beginning with a new pattern induction.

The differences between the master and slaved process steps are therefore as follows. The master subject makes a prediction and then selects the cell with which to deductively test his hypothesis. Conversely, the slaved subject is told which piece to remove and then required to deductively predict its identity. In other words, the two steps (deduction and selection) are in reverse order for the master and slaved subjects. As a consequence, the master engaged in an active process of cell selection while the slaved subject, because he was directed to the next cell, engaged in a passive process of cell selection. Additionally, the master subject determines his own rate of piece removal so that deductive and inductive processes are free to vary in their proportional utilization of the elapsed time between piece removals. Slaved subjects, however, were paced (i.e., they were told which piece to remove at the time when it should have been removed) and consequently had very little time in which to deductively predict the cell identity. Conversely, the major proportion of time for the slaved subject could supposedly be utilized by inductive processes.

The solution process differences evidentally had no effect on cell prediction performance. As defined earlier, the Cell Prediction score is a measure of deductive products, i.e., predictions from induced patterns. Even though slaved subjects presumably had less time than did master subjects in which to deduce from patterns, slaved and master subjects predicted with equal proficiency (master $\underline{\bar{X}}$ = 27.4, slaved $\overline{X}$ = 27.5).

Perhaps the nature of the pattern hypotheses had an influence on the cell production. The mean number of correctly predicted cells was clearly above chance (18) for both experimental condition groups indicating they both were operating deductively. However, experimenter reports noted that subjects were apparently predicting from subpatterns rather than from complete, 36-cell patterns. If master subjects were, in fact, removing pieces in limited clusters or subpatterns then a great amount of deductive processing time would not be required of the slaved subjects for correct cell predictions. The small range of possible cell values (X or 0) would make any subpattern extension obvious almost immediately. Had master subjects been predicting more distant cells, then the active versus passive deductive processes might have produced greater differences in cell predictions. For this score, then, master and slaved subjects operating under different deductive restrictions nevertheless utilized identical amounts of exposed information to predict cell identities equally well. Furthermore, performances for the two groups indicated that their deductive abilities increased equally from ages 9 to 14.

For the three measures of inductive generations (Pattern Hypothesis Onset, Pattern Hypothesis Accuracy and Pattern Hypothesis Quantity scores), slaved subjects generally performed better than did master subjects. Slaved subjects made earlier and more whole pattern hypotheses and were also more correct with less pattern exposure. These findings are in opposition to Duncan's (1964) demonstration that adult subjects inducted item-pair relationships better when able to freely select information than when restricted in information selection processes.

Again, in accordance with the experimenters reports, assume that the piece removal behaviors were sequenced, for whatever reasons, to facilitate predictions from subpatterns. Since it was the master subjects who controlled piece removals, the master subjects were apparently more immediately concerned with subpattern rather than whole pattern hypotheses (or inductions). These predictions from limited patterns conceivably inhibited master but not slaved subjects. The slaved subjects, since they were not responsible for removing pieces to verify patterns (i.e., subpatterns), were less constrained in considering and thus hypothesizing the nature of the whole pattern. In fact, as mentioned earlier, the slaved subjects had very little interpiece removal time to devote to deductive processes since they had to remove pieces immediately upon being told to do so. As a result, slaved subjects had an opportunity to devote more time to inductive (pattern generation) operations than did master subjects. Moreover, the motivation for utilizing all available time for inducing an overall rather than a limited subpattern possibly resulted from the slaved subjects not knowing where their next prediction cell would be located. Knowing that they were responsible for correctly predicting additional but unknown cells, the most reasonable strategy involves forming whole pattern hypotheses to subsume any and all cells in the matrix.

If the slaved subjects had more time available to induce whole patterns and if they were indeed motivated to do so, then one would predict better slaved than master performances on measures of whole-pattern inductions. As mentioned earlier, this slaved subject superiority actually occurred on the three inductive measures. Slaved subjects verbalized hypotheses earlier and more frequently than did master subjects and were correct with less exposed information.

Additionally, the Time score indicates that slaved subjects generally had 5.4 seconds longer than master subjects in which to complete the task requirements. This additional time for slaved subjects could very well represent that amount required for deductions after being told which piece to remove. With the subject and experimenter confounding, however, the score is an invalid measure of deduction time for slaved subjects.

To digress momentarily, motivation for the master subjects to operate from sub- rather than whole-patterns possibly involves the responsibility of selecting cells. Obviously, if one extends available information to adjacent cells rather than to more distant cells, the operation is less risky and more assured of success. Also, the small range of possible cell values (X or 0) plus the ready occurrence of subpatterns in these tasks facilitates correct cell predictions.

Another issue of major concern in this study was the developmental change in subjects' performance. The Cell Prediction score indicated that deductive abilities gradually and similarly improved with increased age for both master and slaved subjects. To discover the growth rate of inductive abilities, one must look primarily at slaved subject performance on inductively based (Pattern Hypothesis Onset, Pattern Hypothesis Accuracy, and Pattern Hypothesis Quantity) scores.

The slaved subjects were almost compelled to devote most of their time to inductive pursuits because of the task procedures. For these three inductive measures, slaved subject performance was generally better than master subject performance (see Table 6). However, at ages 13 and 14 performance for the slaved and master subjects were generally equal on the three inductively based scores. Since deductive abilities of the master and slaved subjects were similar across all ages (Cell Prediction score), it must be an increased improvement in inductive abilities which accounts for the converging master and slaved subject pattern hypothesizing performance. A reasonable interpretation is that after the induction ability develops to a certain qualitative level (ages 13 and 14), induction time restrictions cease to be a limiting factor. For master subjects, ages 9 through 12, the immature form of induction ability cannot be as fully utilized as with the slaved subjects since induction and deduction processes share an amount of time which is almost identical with that utilized by only induction processes for the slaved subject. Apparently, however, by ages 13 and 14, the inductive ability has matured to the degree that the coordination and time sharing requirements of master subjects no longer delimit the quality of whole pattern inductions.

Thus, it appears as though deduction abilities on this task were similar regardless of the respective amount of time available to the master and slaved subjects. Induction ability, however, appeared related to time restrictions until age 13 and 14 at which time master and slaved subjects induced whole patterns appropriately equally.

The final issue of concern involves stimulus appropriateness. Performance on all measures indicated that the stimuli constituted a wide range of difficulty. Furthermore, the stimuli were apparently suitable for eliciting differential performance for the master and shared subjects on four of the five measures. Even with the utilization of differentially different stimuli, the induction plateau occurred consistently at ages 13 and 14 rather than at different ages as a function of pattern difficulty. Actually, from a post hoc analysis of mean ranks across all scores (AS--1.6; AC--1.8; C--2.6; AV--5.3; DS--5.3; and H--4.4), the patterns are most simply classified into easy (AS, AC, and C) and difficult (H, AV, and DS) classes.

The pattern hypothesizing scores suggest that pattern symmetry actually inhibited whole pattern inductions by master subjects. The symmetrically ordered binary elements apparently facilitated subpattern inductions to the detriment of whole pattern inductions. Moreover, the obvious simplicity of these subpatterns allowed master and slaved subjects to deduce equally as well even while the two groups emphasized different pattern orientations (i.e., whole versus subpatterns).

In summary, the results indicate that subjects who were unrestricted in the time allotted to deductive processes and subjects who were required to deduce within a limited time period performed equally on the deductive, cell prediction tasks. On the other hand, those (master) subjects without time restrictions but with the responsibility to actively verify their inductions did not induce the whole pattern as early, as often, or as well as those (slaved) subjects who were restricted in time but who were without the active deduction responsibility. The comparable inductive performance for the 13- and 14-year-olds in the two experimental condition groups was interpreted as a result of an increased growth in inductive abilities such that the induction time restriction was no longer a limiting factor.

CHAPTER IV

SUMMARY AND IMPLICATIONS

Summary

Experiment I

Basically, Experiment I examined information utilization performance as it applies to inducing incomplete pictures. Information utilization was operationally defined as that proportion of a covered picture exposed when correctly induced. The results indicated that with increased age, subjects improved in the picture exposure requirement. While the amount of exposure decreased from 62% at age 5 to 52% at 11, the improvement was not monotonic. A performance plateau occurred at ages 5 and 6 and at ages 8 to 11. While occurrence of the developmentally earlier plateau was unsupported by related research, occurrence of the plateau between ages 8 and 11 was similar to the Weir and to the Westcott findings.

A result in the present study different from explicit Weir findings was the general similarity in onset of the information utilization performance plateau. The use of four differentially difficult stimuli in the present study failed to elicit a plateau which varied in onset as a function of stimulus difficulty. This finding, however, was consistent with an earlier Cox and Fletcher research finding involving picture stimuli and subjects ages 4, 6, 8, and 10.

Two additional measures related to inductive reasoning were important to the current study. One such measure, strategy employment, indicated the efficiency of subjects' picture exposure behavior. In uncovering a picture, subjects could either remove pieces which did or did not cover some portion of the picture. Those pieces removed which were "on target" divided by total pieces removed operationally defined this measure. Results indicated that subjects improved monotonically, from 81% (age 5) to 95% (age 11), in their efficiency of piece removal for picture exposure.

The other additional measure indicated the rate of subjects' verbalized hypotheses. Asked to verbally hypothesize or induce the picture identity at regular intervals, subjects indicated a generally constant rate ($\underline{\bar{X}} = 4.0$) of verbalizations across all ages (5 to 11).

Overall, the results indicated separate growth rates for the proportion of exposure required before correctly inducing the picture, for the efficiency of uncovering the picture, and for verbalizing picture hypotheses. Apparently, the general improvement with age of picture inductions is facilitated by monotonically improving pattern exposure behavior even though at ages 8 to 11 subjects level in their ability to utilize exposed information.

Experiment II

The second experiment, in an extension of the age levels tested, investigated inductive and deductive reasoning performance on more conceptually based stimuli. Subjects, ages 9 to 14, were required to gradually expose symmetrical patterns of binary elements in an effort to both induce the overall pattern and, from this pattern hypothesis, deduce individual binary elements.

Results indicated that subjects almost always improved with increased age in their deductive predictions regardless of whether deductions were actively or passively tested. (The subject either actively chose or was told, respectively, which pattern element to predict.) For the induction measures, the passively deducing subjects generally induced overall patterns earlier, more often, and more correctly with less information than did the actively deducing subjects. Maintaining the somewhat parallel performance, the two different deducer groups improved their inductions until ages 13 and 14 at which time induction performances for the two groups became generally similar.

The interpretation was that induction performance, while developmentally improving, apparently depends somewhat on utilization time availability, at least for ages 9 to 12. Also, the subjects who were required to actively test deductions apparently induced subpatterns to the detriment of whole pattern inductions. Deductions improved across all ages apparently unaffected by time availability or the method of deducing.

From both studies, the ability to induce pictures and patterns evidently improves with increased age. Subjects as young as five years of age are able to induce on incomplete pictures and subjects at least as young as nine years of age are able to induce arbitrary symmetrical patterns. Furthermore, as is often suggested, deductive abilities also generally improve with increased age. However, on picture induction tasks, related or component abilities develop at different rates and even temporally level at certain ages. Furthermore, pattern induction abilities, while improving with increased age, are apparently functionally related to the availability of processing time and the requirement to actively test one's own deductions.

Implications

Psychological Considerations

As suggested earlier, inductions on perceptually based stimuli emphasize memory based rather than generational processes. For the picture stimuli, it would appear that subjects were linking partial information to information which they already had stored in memory. The linking process of generating a common referent for paired items has been labeled elaboration (Rohwer, 1972). However, in Experiment I, an additional process is possibly operating. Subjects supposedly have to search memory for an image as well as generate a link between the presented incomplete information and the retrieved memory image.

Induction, then, as a generational process should be investigated without including memory based processes. A way to eliminate confounding the search and generate processes is to utilize conceptually, nonmemory based stimuli. This way, subjects cannot resort to stored information but, as a valid indication of induction, must generate hypotheses that have never been encountered before. However, from Experiment II, it is obvious that presenting binary elements in symmetrical patterns produces undesired and easily predicted subpatterns. Both the binary and the symmetry characteristics apparently facilitated master subjects' subpattern inductions and therefore cell deductions to the detriment of whole pattern inductions. Use of multivalued elements arranged asymmetrically may help differentiate inductive and deductive performance. The use of more than two elements would increase the range of possible pattern sequences thereby requiring subjects to offer more divergent hypotheses in all stages of pattern exposure. Furthermore, asymmetrical rather than symmetrical patterns would reduce subpattern occurrence hopefully resulting in subjects attending to the overall pattern as required.

An additional issue is the time availability for inductive and deductive processes. Posner (1965) has suggested that the two processes of rehearsal and transformation compete for processing availability in limited-capacity short term memory. Induction and deduction also basically operate in short term memory and, consistent with the findings of Experiment II, apparently compete for or at least interact in a limited processing unit. An extended series of studies where time restrictions were varied would indicate the inductive and deductive time requirements and, if desired, their developmental changes.

A third consideration is derived from the results of the second experiment where the time available to induction and deduction apparently interacted with the age variable. Deductive abilities generally improved with age and in a similar manner regardless of time availability but the inductive abilities, while also generally improving with age, emerged slower for the group (master) with less inductive time supposedly available. Parenthetically, had the subpatterns not occurred then master-slaved induction differences may have been accentuated even more than they were. Thus, the performance time and age relationship to deductive and especially inductive reasoning requires further investigation. Again, the investigation would be facilitated by using multi-valued elements in asymmetrical patterns.

Educational Considerations

Extensions of the above mentioned psychological considerations have educational implications, especially for subjects for whom inductive and deductive abilities are developing and emerging. The specification that induction be studied as generational but not memory based processes suggests that educational practices should emphasize the act of hypothesizing without recourse to easily obtainable hypotheses and theories generally considered to be valid interpretations. For example, in history, inductions could be elicited by hypothesizing reasons for various ethnic groups settling in various parts of the country. In social studies, students could hypothesize reasons why some words actually phonetically describe their meanings or why various cultures have a different member of words to describe the same object or occurrence. In science, students could hypothesize the origin of the universe or some other problem which is equally baffling to the experts.

The process of making sense out of necessarily incomplete information is considered by this author as representative of these challenging activities one often finds after leaving the confines of the classroom. Ideally, if one were to teach induction, the problems encountered should be without a correct immediate answer for both teacher and student. Developing some exciting course work in this area, Thomas (1972) requires subjects to solve problems by generating hypotheses and following their deductive extension to some type of conclusion. Children, approximately eight-years-old are presented hypothetical problems in comic book format and are taken step-by-step through a series of adventures designed to elicit and subsequently test some reasonable hypotheses. An example is the case where three children are reportedly ill from lead poisoning and a student investigator assists medical authorities in discovering the possible and actual way the sick children obtained the lead.

Following up on the time availability consideration, educational practices should precisely delimit when inductions and when deductions are required. Students would then be free to offer as many hypotheses as possible without being liable for testing any of them. In this way, the competitiveness of each process in short term memory would be removed allowing maximum utilization of the respective ability. Furthermore, in keeping with this study's results, subjects should be encouraged to maintain an overall emphasis for categorizing or inducing patterns in order to avoid inducing a limited pattern (subpattern) which explains only the immediate but not the more global information. Conversely, students should also be requested to test some or all hypotheses without presenting new hypotheses or theories. Possibly the students would recognize that there are two competing but complimentary processes which apparently have different growth rates and require different orientations.

Finally, while the time restrictions may have limited immediate implications for students, teachers and curriculum designers would do well to understand the general time requirements of inductive and deductive abilities. Subjects cannot be expected to perform adequately if the time allotted to either or both processes is below the minimum requirement. A child unable to give an immediate answer may do so because of the inadequate time available for the required process. While the time restrictions will probably only be a minimal performance determining factor, the restrictions and especially their developmental changes should be considered.

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APPENDIX A

INDUCTIVE REASONING--A LITERATURE REVIEW AND EMPIRICALLY ORIENTED CONCEPTUALIZATION

William F. Cox

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ABSTRACT

INDUCTIVE REASONING--A LITERATURE REVIEW AND EMPIRICALLY ORIENTED CONCEPTUALIZATION

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This paper reviewed (a) conceptualizations, (b) research, and (c) theories of inductive reasoning and, in turn, proposed both a behaviorally-oriented definition and matching process model. The overall conclusion was that, in spite of the pervasiveness and importance of induction as a knowledge generation process, research and theoretical activities indicate diverse psychological conceptualizations. Psychologically oriented definitions of induction reflected original philosophical ambiguities concerning empirical validation of both the nature and evaluation of epistemological processes. Even with attempts to redefine, rename, and subjugate induction to deductive logic, the inferred processes of induction exist in the scientific method, and in problem solving definitions and their models. Giving closure and direction to various conceptualizations, the requirement of stimulus incompleteness was offered as a primary condition for defining induction. A review of research in related areas suggested that stimulus, organismic, and response variables all contribute to what may be considered rule-determining behavior. The proposed model, emphasizing encoding and hypothesizing behaviors, was supported by experimental research findings. An overall implication was that additional, specific research is required prior to constructing a curriculum for reasoning inductively.

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INDUCTIVE REASONING--A LITERATURE REVIEW AND EMPIRICALLY ORIENTED CONCEPTUALIZATION

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Ideally, psychological research and curriculum development efforts should proceed as a cooperative venture. As a result, curriculum development decisions regarding stimulus, organismic, and response variables are made with reference to specific research findings. The developmental period where programs should begin, how and when to increase stimulus complexity, when to terminate program efforts, and what transferrable effects are expected are all examples of researchable questions.

The curriculum area of interest in this paper is inductive reasoning. However, in a superficial examination of the research literature, one is immediately aware of the numerous labels and, ironically, the appalling lack of research information available on inductive reasoning. As a result, educational programs on inductive processes are evidently not supported by appropriate research findings.

The absence of empirical investigations is unusual for a reasoning process so theoretically interesting and practically important. Generally defined, induction involves reasoning from particular to general or from an individual case to a broader spectrum. Often inductive reasoning involves inventing a model, rule, or law to describe observed and future conditions. The case of Newton hypothesizing the nature of gravity from a single but highly "momentous" instance is an example of reasoning inductively.

Man's progress, both ontogenetically and phylogenetically, is reflected in his ability to propose and theorize beyond what he currently knows. This induction or knowledge generation process is reflected in the entire range of human activities, from children acquiring preestablished knowledge to scientific observations and subsequent attempts to make sense of information. However, the importance of generation activities is often overshadowed by the obviousness and more time consuming nature of knowledge verification activities. While these verification behaviors solidify what we suspect to be "true." the act of generating the suspected nature of information must come first.

The inclusiveness of such generation processes does not automatically guarantee their representation in educational curriculums, however. Few programs emphasize inductive and hypothesizing processes and even fewer programs, if any, teach knowledge generation skills. Induction processes are generally only incidentally acquired in the learning process.

It is the incongruity between pragmatic importance and educational emphasis which initiated the production of this paper. The ultimate goal is to produce an empirically based curriculum in inductive reasoning. The first step toward that goal, then, is the accumulation of a knowledge base through a literature review. A natural second step is to suggest appropriate follow-up research. Therefore, to guide curriculum research and development efforts, the following paper is offered. Historical conceptualizations, functional considerations, theories, a proposed model, and research implications are discussed in that order.

Historical Conceptualizations of Induction

Historical reviews very often provide a frame of reference for viewing contemporary issues. This section provides a highlight of the historical aspects of induction as related to those of deduction, scientific method, and problem solving.

Philosophical Bases for Induction

Philosophy, being the parent of psychology, provided the early Zeitgeist for explaining the nature of mental processes. Philosophically, classical logic was a means for discovering thought process structures and normative laws of the mind. The child, psychology, in turn considered logic as a model of mental functioning.

However, with the development of experimental methods in psychology and the refinement of deductive rigor and logical systems in philosophy, the parent - child relationship suffered. Piaget (1960) describes four possible relationships existing between the disciplines of psychology and philosophy. Platonism, from the early work of Bertrand Russell and A. N. Whitehead, conceives of logic as a non-psychological and experience-independent system of universals. Piaget's expected criticism, the question of how the mind comes to discover such universals, remains unanswered. A second relationship, conventionalism, maintains that logical entities exist as conventions or generally accepted rules. The critical question from Piaget this time is why the conventions are so successful and effective in application. The third possibility, held by the Vienna Circle, is that of a well-formed language. Here purely logical relationships, with the aid of appropriate semantics, may be used to express and therefore test empirical truths. This viewpoint, however, apparently assumes a fully developed system of language. The fourth logical relationship, operationalism, first associated with the physicist P. W. Bridgman in the 20's, views sets of psychological activities or operations as synonymous with concepts. Knowledge is thus based on operations which, also according to Piaget, play an indispensable role in logic.

Thus, depending on the theory, the logic of cognitive activity is explainable in philosophical and/or psychological terms. In addition to philosophical-psychological distinctions, a further clarification of induction occurs when contrasted to the more rigorous logical form of deduction.

Definitions and characteristics of deduction. To help understand the philosophical issues of induction, first consider the concept of deduction. The name most frequently associated with the development of logic, and more specifically deduction, is Aristotle. However, Aristotelian logic, based on a pattern of formal inference known as the syllogism, is only one kind of formal logic. Following the demonstration by George Boole that algebra combines easily with logical operations, more generalized systems of logic developed. Diverse fields such as engineering, genetics, and mathematical computers now employ these "new" forms of logic. Even so, symbolic logic remains as our primary investigatory tool into the science of reasoning.

To evaluate an argument or conclusion of the reasoning process, format and rules of deduction are used. Consider first the content and structure of the format. To the layman, deduction means proceeding from general to specific or from more to less general truths (Jevons, 1913). Jevons is quick to note, however, that in deduction we are developing the consequences of a law. Dewey (1938) similarly defines deduction with an added emphasis on the methods of employing generalizations. The emphasis recently, however, is on establishing the necessary and conclusive nature of deductive arguments: i.e., "in a valid deductive argument, if the premises are true, the conclusion must be true (Brennan, 1957, p. 1)" and "a deductive argument involves the claim that its premises provide absolutely conclusive evidence (Copi, 1967, p. 4)."

Because of the emphasis on the absolute nature of the conclusions, inferences between statements are dependent only on the connection between those statements. Therefore it is appropriate to say that the conclusions do not extend beyond the elements as stated in the premises. This is true even when content restrictions (distribution of terms) exist concerning whether all or some of the premise subjects do or do not possess the referenced quality.

Structurally, deductive arguments typically involve three propositions: a major premise, a minor premise, and a conclusion. However, premises of informal arguments may not be explicit but only implicitly assumed. Without belaboring the point, it should be obvious that logical syllogisms (deductive) adhere to a somewhat typical structural format and contain conclusions that follow necessarily and conclusively from the premises.

To know when conclusions are absolutely conclusive, we use rules of inference. Through the use of such rules we can say whether or not a conclusion is valid. (Describing these rules is beyond the scope of this paper and the reader is referred to appropriate textbooks of logic.) According to Suppes and Hill (1964), "valid rules ....never allow us to go from true premises to a false conclusion (p. 65)." But the reader must be careful to distinguish between the two terms, true and valid. Logical validity applies only to the formal correctness of the conclusion and not to the material truth of the premises.

The distinction between logical truth and validity cannot be too strongly emphasized. The logician is concerned only with the correctness or validity of the completed reasoning process. His task is to determine whether the conclusion reached follows from the premises. By the nature of the rules, a valid conclusion is therefore necessary and conclusive. However, the actual process of reasoning is not the logician's concern. Furthermore, establishing the truth of premises is also not the logician's concern. The premises are accepted as either true or false. Therefore, the case could exist wherein a false conclusion is accepted as valid because a premise assumed to be true was, in actuality, false. An appropriate example from Copi (1967) is as follows:

> "All trout are mammals.
> All mammals have wings.
> Therefore all trout have wings (p. 5)."

The argument is valid even though the premises are materially false.

Summarizing, philosophers and logicians utilize rules of format and evaluation for establishing the validity of deductively derived conclusions. While the conclusions must follow in a necessary and conclusive manner from the premises, the material truth of premises and conclusions are not evaluated. How these philosophical definitions and characteristics of deduction compare to those of induction follows next.

Definitions and characteristics of induction. Induction, as a principle in logic and philosophy (excluding mathematical induction), does not enjoy the neatness and rigor of conceptualization accorded deduction. In fact, Westcott (1968) contends that induction has historically existed on the opposite end of a continuum of intuition that begins with acquisition of knowledge as perfect truth without constraints of reason, through intuition as an apprehension of limited truths applicable to the intellect, to intuition (induction) as conventions or probability statements suitable to empirical tests. Emphasis in this section is on the more empirically oriented characteristics of induction.

Definitions of induction have not substantially changed from Aristotle's formulations. Philosophers (i.e., Dewey, 1938; Jevons, 1913; Medawar, 1969; Spearman, 1923) generally agree that induction means going from less to more general terms, often for discovering laws that hold over repeated observations. However, statements more specific than the particular-to-general theme exist in terms of form and validity that most clearly differentiate induction from deduction.

Inductive statements must do more than summarize, "they must add something more (Medawar, 1969, p. 23)." The early views of Mill suggested that inductive conclusions must be wider than the premises from which they are drawn. Kneale (1949), while stressing the reliance on rules or laws, further suggested a going beyond the limits of actual experience. This quality of going beyond the premises clearly differs from the deductive quality of never passing beyond the premises.

Concerning the structure of inductive arguments, there is little or no evidence available suggesting that the syllogistic format is appropriate. In fact, most accounts of induction ignore this issue with the assumption that premises exist more in an informal rather than a formal structure. Brennan (1957) readily admits that philosophers generally concede the impossibility of arranging induction "in an exact system comparable to deductive logic, with rules and operations of similar precision (p. 176)."

However, as with deductive arguments, we must ask if rules also exist to determine the validity of inductive arguments. Mill's five Canons of Induction, Aristotle's induction by complete enumeration and intuitive induction, and Kneale's (1949) account of recursive and ampliative induction are more concerned with methods of observation and content properties than they are with the structural relationships among premises. Possibly the only exception to the above statement is induction by complete enumeration (of all instances) or complete induction which according to Brennan "is really not inductive inference at all, but a rather convenient summary of what we already know (p. 177)." An even stronger viewpoint (Cohen and Nagel, 1934) is that complete induction "is an example of a deductive argument (p. 275)."

The underlying assumption of all other forms of induction is a reliance, not on explicit rules, but on the principle of the uniformity of nature. Induction thus serves to reveal the patterns and periodicities of nature upon which we may safely depend for purposes of prediction. Therefore, "inductive inference can never give certainty.... if an inductively established law cannot be certain, at least it can be more or less probable (Brennan, 1957, p. 197)." This lack of certainty keeps us from formulating and applying precise rules of evaluation. We are instead more interested in establishing the material truth of premises.

The nature of induction, then, is to generate laws or hypotheses based on evidence or premises whose truth value must be evaluated. According to Cohen and Nagel (1934), "the specific problem of induction is to determine to what extent the samples are fair (p. 278)." We do not know to what extent the examined instances are representative of an entire class to which they belong, hence we must rely on the assumed regularity of nature to support our arguments.

Major differences between deduction and induction can be summarized as follows. Deductive arguments are evaluated by fixed rules of inference to determine the logical validity of conclusions that must be necessary and conclusive and within premise constraints. Inductive arguments rely upon observed regularities of nature to construct hypotheses or laws that are not necessarily absolute but are more or less probable. More precisely, the proper contrast is not between deductive and inductive inference, but between inferences that are necessary and inferences that are probable (Cohen and Nagel, 1934).

Since induction cannot be validated by formal means, it is not without criticism from theorists who insist on accepting only purely formal systems. Conceptual issues of continuing interest are highlighted below.

Validity of induction. The problem of logical justification of induction has existed for at least the last hundred years. According to Medawar (1967), Whewell used the term but then later felt he might have dropped it, and Neil restricted the term to mean only the act of testing a scientific conjecture. Popper (1959) claims that "There is no such thing as induction (p. 40)." He further suggested that the criterion of scientific admissibility be phrased in the negative sense: the possibility must exist for an empirical scientific system to be refuted by experience. Thus, inductive statements are not admissible because by their sense of probability they cannot be refuted. Medawar (1967) claims that the word induction lacks the qualities that would justify its retention in a professional vocabulary. Such a rejection by Medawar appears based on a lack of agreed upon definition among philosophers.

Other critics are less harsh. For Jevons (1913), induction and deduction are inverse operations: all knowledge is inductive whereas all reasoning is founded on principles of deduction. In either case, however, Jevons claims that the conclusions never pass beyond the premises.

David Hume questioned the concept of induction in a more general way. He contends that generalizations are nothing more than the force of habit or animal faith. Since from experience we cannot know the future but only the past; habit and custom alone lead us to believe occurrences in the past will similarly occur in the future. Medawar (1969) extends the criticism even further by suggesting that not all knowledge originates in the senses but to some extent is inherited or instinctual: e.g., a bird's song exists as a transcription of a chromosomal tape recording.

Additional appeals for conceptualizations separate from empirical justification appear similar to the Freudian notion of an unconscious influence on conscious processes. Westcott (1968) and Koestler (1964) both emphasize that the occurrence of intuition, or the creative leap, is contingent upon a release from reason and logical constraints. Poincaré is often referenced (e.g., Rosenblueth, 1970) regarding the unconscious elaboration process that occurs during the incubation stage of invention. He suggests that an aesthetic screening device allows only those harmonious, useful, and beautiful ideas from the unconscious to reach the conscious. Thus, unconsciousness is more superior than consciousness in originality and creativity.

Whether one agrees or not with the conceptualizations of induction, the process of generating hypotheses and generalizable laws must certainly exist. Nagel (1963), in a summary of various positions on induction, has suggested that many students of the discipline have dismissed the problem of justifying induction in favor of a concern for its rationality. Medawar (1969) argues that induction is parallel to deduction since the former processes (of generalization) are themselves grounds for truth. Admitting the validity of the generative act but citing numerous criticisms of the term induction, Medawar suggests use of the term hypothesizing. Taken together in a symbiotic existence, hypothesizing and verifying processes are labeled as the scientific method. As discussed in the following section, the two processes form a complementary act that is typical of scientific endeavors.

Relation of induction to the scientific method. A scientist attempting to bring order to a body of evidence supposedly utilizes two complimentary processes: "he must invent or generate his theory, and he must trace his way along the deductive path... to the proving ground provided by his experimental predictions (Wallach, 1967, p. 39)." Both processes were at one time (Jevons, 1913) considered as three steps in the process of induction: (a) framing a hypothesis about the character of a general law, (b) "deducing" consequences from that law, and (c) observing whether the consequences agree with the particular facts under consideration. The distinction between having an idea and testing the idea led first to the phrase inductive - deductive and then to the hypothetico-deductive terminology (Medawar, 1969).

The first phase, inducing or hypothesizing, includes the processes of generation, invention, speculation, intuition, creation and other processes generally considered outside the realm of deductive logic. This amplification act may best be characterized as a knowledge expansion process. The second phase, deduction, is generally characterized (Medawar, 1967, 1969) as a logical process of testing, deriving, and inferring consequences of the first phase results.

To Wallach (1967), man's thinking in mathematics, science, and art seems characterized by two phases which he calls "expression of possibilities and the analysis of implications (p. 46)." Unfortunately, however, a scientist's account of his own intellectual procedures is often untrustworthy. Supposed objective explanations of the nature of scientific thought emphasize the importance of deduction activities. Perhaps the inordinate proportion of time given to deductive pursuits incorrectly influences their assigned importance. While the scientific method is rigorous and logically conclusive, scientific laws are inductive in origin. Without the generative act of hypothesizing, conceptual advances would never be made. The scientist, according to Darwin (Medawar, 1969), "might as well go into a gravel-pit and count the pebbles and describe the colors (p. 11)."

For illustrative purposes, consider Mendeléeff's invention of the Periodic Table of Chemical Elements. From only partial information about known chemical elements, Mendeléeff hypothesized or induced that element properties repeated themselves periodically after each seven elements. He then deductively tested his hypothesis by not only completing the Table for all known elements but by predicting properties of, as yet, undiscovered elements and by demonstrating that properties of certain elements had been incorrectly established. While this is only one example of the productive results of scientific reasoning, it clearly and dramatically indicates the joint processes of generating and testing.

In summary, philosophical and logical characterizations of deduction emphasize format, standards of construction, and rules of evaluation. As a rigorous system, deductive validity concerns the lawful necessity of conclusions without regard for material or empirical justification. Induction, however, exists as information generation, acquisition, or accumulation. Material truth only determines inductive validity regardless, for some, of supposed epistemological methodology (conscious or unconscious). Despite arguments refuting the logic of induction, the processes represented by the terms induction and deduction constitute the scientific method. How these two stages have been conceptualized for empirical and psychological investigations is the subject of the next section.

Psychological Bases for Induction

This section departs from epistemological and philosophical theories in favor of more empirically based conceptualizations. Major emphasis is placed on the definitional and experimental aspects of induction. Here, as with the previous section, deduction is presented as a contrast for induction, the validity of induction as a concept is examined, and induction is compared this time to various issues in problem solving. Additionally, a tentative, working definition of induction is offered.

Definitions and characteristics of deduction. This psychological section needs little elaboration beyond its philosophical counterpart: the same type of logical characteristics are employed for analyzing reasoning processes. The system, such as symbolic logic, again consists of rules and laws that apply only to the products of reasoning and not the processes themselves. Furthermore, the conclusions, to be valid, must follow necessarily and absolutely from the premises or assumptions. Various systems other than symbolic logic enjoy more exposure under psychological orientations than under the more historical philosophical orientations. Piaget (1970) notes that these systems may exist in some of the following content areas: biology, physics, mathematics, linguistics, social sciences, perception, and physiology, and have at various times been applicable to psychology.

While logic (deductive) and psychology can coexist, a clear distinction between the two should be maintained. According to Guilford (1967), the purpose of logic is to develop rules for evaluation or testing while the purpose of psychology, as a science, is to objectively describe how products of information develop and are utilized. The distinction is difficult to hold when confronted with Piaget's (1970) view of symbolic logic as an instrument for psychology. For him, logic has a double relation to psychology: psychological theory can be constructed in terms of modern logic, and intellectual functioning develops in the direction of formal logic.

Anyone familiar with Piaget's work will agree that a highly formalized and somewhat esoteric notational system exists for describing the development of intelligence. While other theorists and researchers (e.g., Sigel and Hooper, 1968) have used logic to describe intellectual development, Piaget is singularly mentioned for both his predominance in and contribution to the field.

The purpose here, however, is to indicate Piaget's use of logic for analyzing cognitive development and not to present and elaborate on his theories. By utilizing the logic of mathematical lattices and groups for analyses, Inhelder and Piaget (1958) suggest that only after approximately age 7 do children begin to develop toward logical rigor. Finally, during the last (formal operations) of four stages of development, cognitive activity is described as a pursuit of necessary reason. It is during this stage that "thought proceeds from a combination of possibility, hypothesis, and deductive reasoning instead of being limited to deductions from the actual immediate situation (p. 16)." In other words, as in formal logic, the hypotheses are derived from a calculation of all possible combinations (i.e., the combinatorial system of propositional logic) and are not merely an account of the empirical situation. Research efforts to substantiate the Piagetian application of logic to intellectual development are numerous but not our concern here. It is interesting to note, however, that some researchers are giving more exacting clarifications of such development. Hooper (1969), for instance, has indicated that there is a developmental difference in identity and equivalence conservation: equivalence occurring developmentally later since it involves a deductive sequence not found in identity conservation. O'Brien and Shapiro (1968) distinguish between developmental differences in the acts of recognizing versus testing the logical necessity of syllogistic statements.

Briefly summarizing, deductive logic, with its rules for establishing absolute and necessary conclusions, is used to evaluate reasoning products and to describe the genesis of intelligence. Piaget, vanguard of the genetic epistemology school, suggests that intelligence actually develops toward a formal system of logic.

For all the emphasis on deductive necessity, little attention is given to the concept of induction. In fact, only once was a Piagetian reference found on induction: "The essential task of experimental reasoning or induction is that of separating the deducible from the random (Inhelder and Piaget, 1958, p. 224)." The conceptual term"hypothetico"appears often, however, and apparently operates to restructure possibilities already in existence. Broader definitions of induction exist as indicated in the next section.

Definitions and characteristics of induction. Psychological conceptualizations of induction vary from undefined processes to the analysis of relative stimulus values. Those definitions emphasizing undefined processes have not departed in spirit from philosophical orientations. Empirically oriented definitions generally reflect experimental tasks which involve incomplete perceptually or cognitively based stimuli. Theoretical accounts of induction reference the underlying cognitive structure and stimulus strength or probability values. A closer look at these various conceptualizations of induction follows.

Prior to proceeding, however, the reader should also recognize the breadth in number of labels for inductive processes. For example, terms such as creativity, insight, probability, intuition, guessing, and hypothesizing are used somewhat synonymously with or at least overlap the conceptualization of induction as presented here. A specific discussion on the term inference is contained in the later section, Status of Inductive Reasoning.

The first set of definitions, those which involve arriving at conclusions or judgments without an awareness or ability to verbalize intervening steps, is most often classified as intuition, insight, or guessing (Westcott, 1968). While similar to philosophical orientations, these definitions form the bases for psychologically-oriented research, hence they are included here. Westcott, after reviewing the literature, suggests that for a conclusion to qualify as "intuitive," how that conclusion was reached must ordinarily remain unknown. He (pp. 37-41) cites the following for support: DeSanctis ("immediate act of cognition"), Valentine ("judgments of which the grounds are unconscious"), Hebb ("right conclusion without being able to state the evidence which determines it"), Berne ("without....being able to formulate... how he came to his conclusions"), Board ("unconscious or otherwise unavailable for conscious delineation"), and Bouthilet ("the capacity to make correct guesses without knowing why").

Bartlett (1958) suggests that information can be developed to a conclusion by three distinguishable processes: (a) all moves are formulated; (b) no moves are formulated until after the conclusion is reached; and (c) a mixed process where some moves are formulated while others are guessed. The guessing procedure refers to accepting a conclusion without assigned steps. Polya (1954) also emphasizes the role of guessing in mathematical induction. He insists that while natural cleverness is required, being a good guesser is equally important. In fact, Polya suggests that we must learn to guess so that better chances exist for our judgments to be correct. Bartlett (1958), in agreement, thinks the most fruitful line of experimentation may result from using an unverbalizable sensitivity to evidence.

Other researchers, while using different construct terms, also emphasize solving of new and inexplicit problems through undefined processes. Wallas (1926) suggests that creation occurs from apparently unrelated evidence in two stages of thought: incubation and illumination. Spearman (1931) suggests that creation and insight are absolutely coincident and represent the supreme level of mental content generation. For Bruner (1969), an inexplicit reliance on one's analytical crafts for grasping meanings and problem structures constitutes intuition. Supposedly, intuition is the generation of hypotheses; the worth of which is then tested through techniques of analyses.

Piaget (in Elkind, 1967) claims that intuition exists as a substitute mechanism prior to the development of logic. Intuition is defined as "making assertions without attempts to support them with facts (p. 29)." The mechanisms of intuition are also thought to develop according to rules of logic starting at a primary level of nonreversibility and rigidity and proceeding to a preparatory stage (articulated induction) for the operation of reversibility. "Intuition is the highest form of equilibrium attained by the young child (p. 48)."

The next classification of inductive definitions involves those of a more empirical orientation. The substitution of empirical for philosophical orientations is exemplified by the process of evolution taken by Westcott's (1968) conceptualizations. Originally defined to include unconscious processes, his definition of intuition now reads, "the process of reaching a conclusion on the basis of little information which is normally reached on the basis of significantly more information (p. 41)." This definition specifically permits a statistical determination of differences between normally required information and significantly more or significantly less information.

Perceptual experiments have generally dominated research on the utilization of partial evidence. Motivation for some of the earlier studies (Mooney, 1957a, 1957b, 1957c; Mooney and Ferguson, 1951; Street, 1931) developed from the Gestalt tradition which emphasizes the concepts of closure and goodness of stimulus organization. Gollin (1960, 1961, 1962, 1965), Smock (1955, 1957), and Messick and Hills (1960) similarly used incomplete pictures with the additional feature of a gradual increase in the amount of picture exposed. For the above mentioned studies, however, there was a noticeable lack of prerequisite operational definitions. Messick and Hills, and the Smock studies were more concerned with the related construct of intolerance for ambiguity and only the later studies by Gollin (1962, 1965) were founded on a training-based stimulus generalization paradigm. Cox and Fletcher (1971) also used a task involving gradual increase of picture exposure but operationalized their definition of induction as "utilizing information about some members of a class or scheme to support an inference about the whole or some larger portion of the whole (p. 3)."

Conceptually, one might say that the numerous investigations by Torrance on creativity are concerned with induction. He (Torrance, 1967) defines creativity to include "the process of becoming sensitive to... deficiencies, gaps in knowledge, missing elements... formulating hypotheses... (p. 73)." The definition, when compared to Bartlett's (1958) appears more process than product oriented. Torrance is concerned with operationally defining the kinds of abilities, mental functioning, and personality characteristics which facilitate or inhibit the process. Bartlett insists that thinking (or in other words, gap-filling) should be experimentally determined through a series of steps which are expressed, or articulated, and not simply left to the imagination of either the experimenter or operator. The gap-filling of interest to scientific thinking, according to Bartlett, is where all of the constituents are not available and/or there is not a predefined way in which to utilize this information. The above viewpoint sounds very much like "going beyond the information given (Bruner, 1957)" to new insights.

With an emphasis on both processes and products (and content), Guilford (1967) defines the act of generating information from given information as divergent production. This definition has different connotations, however, depending on the product form utilized. When the operation of divergent production occurs on forms of information which Guilford classifies as units, classes, and relations, it is memory based. That is, a memory search is conducted for purposes of recalling currently existing information. But when divergent production involves the information products of systems (which have never existed before), Guilford claims an organizing activity such as the concept of transfer has occurred in addition to retrieval operations. For example, recalling items previously unconnected to their cues for constructing new sentences involves use of generalized patterns and search models.

Retreating from observable to more theoretical levels (third definitional category), Bartlett (1958) emphasizes the role of schemata (organization of past reactions) in gap-filling processes. His phrase of "turning around upon its own schemata" represents a reordering of temporal events into new self-consistent wholes. Similarly, Bruner (1964) emphasizes that the goodness of cognitive structure is a direct determinant of the power for generating new propositions and for increasing the manageability of a body of knowledge. Other theorists (Ausubel, 1968; Gardner, 1969; Wertheimer, 1945) also emphasize the role of reorganizing structural elements for the purpose of creating or inventing new relationships.

Additional structural viewpoints include Poincaré (Ray, 1967) who suggests that mathematical creation consists precisely in not making useless combinations. Piaget (1970) maintains that there is a conceptual difference between elements of a structure and those transformational laws which apply to the structures. To him, it is the structure (knowledge) that changes and not the laws, which are immutable. Reinterpreting, if induction exists as a cognitive law, then Piaget would claim that developmental differences are a result only of knowledge acquisition. Specific criticisms (i.e., Ausubel, 1968; Berlyne, 1965) against structural interpretations are similar to those leveled against Gestalt structures: they are often preceptually bound and, in general, are beyond defining.

Research investigating the acquisition and application of mathematical groups (Cyclic, Modulo, and Klein groups) has, at least in these instances (Dienes and Jeeves, 1965, 1970), operationalized structural definitions. After subjects learned the groups, questions were asked to determine to what extent subjects induced the rules. Known as intuition scores, answers were sought to questions for which there had been no direct evidence. That is, subjects predicted rule generality from a sequence of instances just as a series of logical operations can be composed into one similar subsuming operation.

An issue closely related to structural considerations of induction is the concept of stimulus strength. Hebb (1949) suggests that intellectual invention or insight results from new combinations of sequenced cell assemblies. These cell assemblies are supposedly formed by the firing of single neurons with sufficient strength to unite with other adjoining cells. However, Hebb suggests that having the organization processes too tightly arranged might conceivably interfere with forming the fresh combinations required for insight. According to Hilgard and Bower (1966), Pavlov explains that cortical pattern determination follows from excitation processes which initially are inhibited upon presentation of a negative stimulus but later become facilitated through the process of reciprocal induction. Hull (1935), while referring to psychological rather than physiological entities, similarly speaks of novel arrangements (of behavior segments) for insightful solutions. Substitution of members in a response pattern occurs when goal stimuli integrate various habit family hierarchies which lead to the same goal. Classical S-R theory (Hilgard and Bower, 1966) labels the positive correlation between response tendencies toward two stimuli as positive induction. However, the case also exists where response rates are negatively correlated and is appropriately called negative induction. Skinner also uses the term in a similar manner and, as expected, avoids using the term insight. To him (Skinner, 1953), originality is not involved in thinking: problem solving results from manipulating variables that lead to response emission.

The above definitions of induction, however, appear more closely related to mechanical acquisition through proximity rather than to the creating or inventing oriented definitions discussed so far. That is, defining characteristics emphasized, not active processes, but only a passive and receptive existence. A major critic of habit strength and association theories, Berlyne (1965) contends that most theories are unable to distinguish between autistic thinking or free association and directed or goal oriented thinking. As an alternative, he calls for the inclusion of transformational thoughts into the stimulus and feedback units for linking purposes, thereby revealing the process which causes the chain of thought. Kendler and Kendler (1956, 1958, 1961) additionally argue for the inclusion of motivational and reinforcement variables on "inferential" behavior and specifically present evidence which is unexplainable by Hull and Skinner concepts of anticipatory goal responses and chaining.

Still another way to view induction is in terms of probabilities. Brunswick's (1956) theory of probabilistic functionalism emphasizes the optimal usage of cues which are not perfectly correlated with the object being inferred. The bases from which subjects make inferences are subjective counterparts of environmental distributions known as distribution hypotheses. A considerable amount of research (e.g., Beach, 1964; Hammond, 1970) exists in this and related areas (e.g., statistical decision theory) but will not be reviewed because of its tangential relationship. However, Carnap (1960) makes a conceptual distinction between statistical and inductive probability which should be mentioned. Basically, the statistical concept of probability means the relative frequency with which an event occurs within a population, either real or potential. In a certain sense it is a descriptive characterization. Inductive probability, on the other hand, is ascribed to a hypothesis with respect to a body of evidence. Hypotheses are graduated in truth value on a scale of probabilities. Carnap suggests that even among scientists this strength of support or degree of confirmation given to a hypothesis (H) on the basis of evidence (E) is a comparative rather than an absolute judgment. Inductive probability, in contradistinction to statistical probability, cannot be ascribed to the material object alone but includes the observers' evaluations. While Bayesian theory combines induction and statistical principles to determine subjective probabilities from past events, it apparently lacks the methodology for simulating personalistic evaluations.

To summarize, characteristics defining induction vary widely, from those totally observable to those totally unobservable. Definitions emphasizing the existence of immediate solutions and undefinable processes are more often labeled intuition or insight rather than induction. Piaget suggests that intuition precedes the development of deductively based operations but it is unknown to what extent induction, in actuality, is taken over by logical processes. Other definitions emphasize factors such as stimulus incompleteness, stimulus structure, cognitive structure, stimulus strengths, and stimulus or cue probabilities. Generally, theoretical definitions are not mutually exclusive and researchers often operate without explicit definitional bases. The "logical conclusion," then, is that induction currently exists as a less than explicit psychological concept.

For some, however, the issue is not that induction needs a stronger conceptualization but rather that induction is an invalid psychological concept. The next section examines some critical viewpoints especially as they relate to cognitively oriented definitions.

Validity of induction. The idea that induction cannot really exist apart from deduction is entertained by Ausubel (1968) and Spearman (1923). After criticizing the viewpoint that considers all induction as deriving from deduction, Spearman, nevertheless, suggests that induction is ultimately some particular case of syllogistic deduction which, in turn, is a special case of educing relations. The elusive term, educing, is presented as knowledge from a "source other than lived experience (p. 76)," and the term appears similar to previous conceptualizations of intuition. A similar but less circular argument from Ausubel is that inductive problem solving is a subsidiary phase within a deductive approach since provisional assumptions are derived from past experience. Spearman's views are more closely aligned to Ausubel's when interpreted by Guilford (1967): "eduction involves both induction and deduction (p. 110)."

Guilford's (1967) own views, however, are that, after some conceptual reinterpretations, the concept of induction is not needed. He originally proposed that what we make of immediately given information in terms of classes, relations, systems, and implications gives four kinds of induction: (a) classificatory, (b) relational, (c) systemic, and (d) implicational. More elaborate and systematic concepts within his Structure of the Intellect theory now replace these four types of induction. Specifically, the generalizing aspect of induction (to other classes, etc.) is replaced by his product term of transformations, and the concrete-abstract dimensions of induction (which he considers valid in science) are replaced, respectively, by figural and symbolic (content) contrasts. In opposition to Guilford's precise explanation of intellectual factors is the Adcock and Webberley (1971) research finding that reasoning and insight involve a large common factor which could be the capacity to structure complex material into an integrated system.

Definitions of induction as an absence of rules, are reduced, by Piagetian interpretations, to less mature forms of cognition. Piaget (1969) maintains that the absence of logical rigor prevents the child from generalizing and it is irreversibility of thought which causes the lack of rigor. Cognitive processes not governed by reversibility (such as the intuition and insight definitions mentioned earlier) fit the primitive forms of thought that Piaget labels syncretism. He further suggests that intuition, or assertions without accompanying attempts at factual support, becomes an operation, hence deduction, when composable and reversible (see Elkind, 1967).

Contesting the appropriateness of applying abstract logic to reasoning processes, Bruner, Goodnow, and Austin (1958) suggest that much of human reasoning is supported instead by a thematic logic. Basically, the thematic process is of a pragmatic rather than a logical structure; humans tend to work with and prefer empirically reasonable propositions as either hypotheses or conclusions. As a result, the conclusions preferred, in spite of their logical incorrectness (which may be more evident when abstractly stated), are those most consistent with one's own attitudes and values.

Some writers are inclined to emphasize the transfer of prior learning as a primary condition for insight rather than unverbalized factors leading to sudden discovery (see Gagné, 1970). Results from Harlow's studies on learning sets in primates suggest that the capability for insight comes not from the problem structure but from experience accumulated over many trials. Maier's famous pendulum experiment is additionally cited in support of facilitated recall and goal directedness resulting from appropriate instructions.

In spite of criticisms on the nature of induction, its existence is inherent in some definitions of problem solving. This is seen in the next section.

Relation of induction to problem solving. Accounts of problem solving processes are too numerous for a complete and exhaustive review. However, several better known conceptualizations are examined for their inductive components. For this section, induction is considered primarily as a generation or production of hypotheses. For example, induction is inferred in the third step of Dewey's five episodes of problem solving: (a) a difficulty is felt, (b) the difficulty is defined, (c) possible solutions are suggested, (d) consequences are considered, and (e) a solution is accepted. When reduced to three steps by Johnson (1955) and Taba (1964), the inductive step remains as production and inferring generalizations, respectively. More recently (Guilford, 1967), induction apparently underlies steps of formulating or producing possible solutions.

Several (Johnson, 1944; Miller, Galanter, and Pribram, 1960) theories of problem solving rely on models or images but with different emphases. For Johnson, problem requirements force the patterning of a search model that anticipates a gap to be filled. Miller et al. suggest an alternative to the mechanical exercise of searching for a solution. Instead, prediction of sequenced steps is substituted in the TOTE model with a resulting emphasis on an image rather than a plan. While test (T) units remain the same, the operate (O) phase is now predicting and not searching. Similarly, in a related area, Bruner et al. (1958) suggest that the act of forming a concept (concept formation as opposed to concept attainment) is the formation of a hypothesis about exemplars and nonexemplars of a class. Bloom's taxonomy (Bloom, 1956) defines the behavior of synthesizing as arranging pieces and parts to constitute a pattern or structure not previously there. Educational objectives written for synthesizing operations include the ability to propose ways of testing hypotheses and to make mathematical discoveries and generalizations.

Conversely, the role of induction is deemphasized in some theories. The emphasis for Gagné (1970) is instead on the conditions in the learning situation. For example, solution responses must be identifiable beforehand, relevant rules must be recallable, and new rules must be derivable through combining other recalled rules. However, individual differences such as the fluency with which rules are combined into hypotheses are recognized as affecting the problem solving process. Subjects in Piagetian research generally have available the complete set of information needed for problem solution, thus making induction on the basis of partial information impossible.

Conceptualizations that empirically isolate induction from other phases of reasoning and problem solving are few. Problem solving, viewed as stages of induction and deduction, has received research support from Johnson (1961) and others (Johnson and Hall, 1961; Johnson and Jennings, 1963; Johnson, Lincoln and Hall, 1961). These stages constitute factor analytic entities and are experientially based on appropriate stimulus conditions.

To restate a previous conclusion, induction as a firm and consistent definition in psychology is nonexistent. That is, induction is ambiguously defined as intuition, as a substitute for logical operations, as perceptual processes, as acts of creativity, as structural relations and reordering, as a product of stimulus strength properties, as probability values, as a function of deductive logic, as pragmatically rather than abstractly based, or even denied in favor of more precise terminology. Conceptual clarity is further weakened by the ambiguous role afforded induction in problem solving processes. To alleviate some of these problems, a working definition of induction is presented next.

A working definition of induction. To investigate the inductive processes inherent in much scientific work, a sound definition is needed. The scientific work of concern occurs when man invents an understanding of incomplete information (e.g., inventing the Periodic Table of Chemical Elements or categorizing biological systems). Some qualities desired in such a definition are as follows. Unconscious or unexplainable processes and insightful discoveries may very well exist but are not considered. In fact, the only acceptable references to cognitive structure should exist in terms of what has been operationally verified from tests and other recorded behaviors. "Higher level" products of clinical induction, because of insufficiently validated methodology, are secondary to more quantifiable concepts of induction. Finally, to achieve operational validity, the emphasis is on induction as a function of stimulus incompleteness.

Hence, the temporary working definition proposed is: induction is the generation of a reportable hypothesis from only some members (as given) of a class, scheme, or pattern to describe the whole or at least some larger portion thereof. (The term hypothesis refers to a tentative explanation derived from insufficient evidence.)

In summary, from philosophy, psychology inherited logical rules (deductive) by which both cognitive growth and operations are evaluated. Induction as a psychological term varies conceptually from the existence of unknown processes to the utilization of partial evidence for hypothesizing a class or a rule. Appeals to factors such as cognitive structure, stimulus strength, cue probabilities, and the invalidity of induction continue to plague efforts to solidify an acceptable universal definition. A proposed working definition objectively classifies induction as specific stimulus-bound, observable behaviors or skills. To further clarify the concept of induction, the next section presents some research findings relevant to the issue.

Functional Considerations of Inductive Reasoning

Further information for conceptualizing the nature of inductive reasoning exists in relevant research. Results are included from research broader in scope than the induction area of interest and this research is discussed under the headings stimulus, organismic, and response variables.

Research Concerning Stimulus Variables

As early as the 20's, research investigated the effect of changes in material on syllogistic reasoning. Deviations from the normal organization of habits (Thorndike, 1922) and from familiar, concrete materials (Wilkens, 1928) were suggested causes for interferences in reasoning. Later (Sells, 1936; Woodworth and Sells, 1935), three hypotheses accounted for invalid conclusions: (a) ambiguity between logical and everyday language, (b) cautiousness in accepting strong conclusions, and (c) the atmosphere effect of premises. The atmosphere effect, or generalizing influence of premise overtones, continued as a major area of interest for some time (see Vinacke, 1952). Additional research suggested that, in general, subjects were not aware of the atmosphere effect and that high personal convictions could override this effect.

Historically, interest in the effects of content familiarity changed somewhat but did not decline. While the early Wilkens' study presented premises in familiar, unfamiliar, symbolic or suggestive groups, later research (e.g., Long and Welch, 1941, 1942; Roberge and Paulus, 1971) emphasized content groups on a continuum from familiar to abstract. Findings from these studies, however, continued to indicate the relative difficulty of abstract materials, especially for children. However, stimulus relationships as well as content values may also influence inductive reasoning as suggested by findings (Roberge and Paulus, 1971; Seggie, 1969; Snow and Rabinovitch, 1969) that conjunctive and disjunctive rule learning interacts with familiar-unfamiliar content and that induction may exist independently of content (Wetherick, 1969). The next section, therefore, presents some considerations related to stimulus structures.

Influence of structural relations. Stimulus structures play an important role in reasoning tasks. For instance, a melody is immediately recognized in a changed key when not a single note of the original remains. For Simon and Sumner (1968), computer generation of musical patterns provides an aid for psychological analysis of cognitive activity. From letter-series completion tasks, they conclude that pattern extrapolations are based on notions of simple periodic patterns. Additionally, the basic concepts and accompanying rules for combining are parsimonious and relatively independent of specific stimulus materials. The formal language for describing patterns involves: periodicity--repetition in intervals that occur "lawfully"; alphabets--sets of sequentially ordered symbols; compounded patterns--subpatterns of symbol arrangements; phrase structures--as indicated by punctuation; multidimensionality of notes in their relationship; and variation of patterns.

Research closer to the present concern involves presentation of incomplete, cognitively-based stimuli (e.g., serial completion tests). Westcott (1968) very adequately summarizes a history of research on this and related areas of perceptual recognition. For instance, children, operating conceptually on gaps in information, were willing to make longer leaps across such gaps than were older subjects (Mosher) but were generally more inaccurate (DeSanctis). Scores, while lower on speeded than on nonspeeded presentations of syllogisms, were better than estimated by test subjects (Farmer). For inferring categories from reinforcement based cues only (Snapper), success was correlated with the ability to verbalize the categorization principle. From his own investigations on series completion problems, Westcott contends that intuitive thinking (reaching a conclusion on basis of less than normally required information) is an identifiable capacity or tendency; intuitive thinking is stable within, but differs among, individuals. The amount of information taken by an individual is usually no predictor of success but is correlated with confidence in correctness.

A number of perceptually oriented studies using fragmented evidence also reflect conceptual concerns in problem solving, information gathering strategies, and similar areas (Gollin, 1960, 1961, 1962, 1965; Messick and Hills, 1960; Mooney, 1957a, 1957b, 1957c; Smock, 1955, 1957; Westcott, 1968). The Mooney studies suggest that identification of incomplete, black and white drawings occurs instantaneously and with a single fixation. Even when compositional detail varies, results do not change suggesting that objects represented by intrinsic forms have a "stimulus-complex" effect. Elkind, Anagnostopoulou, and Malone (1970) indicate that part-whole perception is mediated by the development of logic-like perceptual regulations. While training on the completed form of fragmented pictures helps, training on the incomplete form helps even more according to Gollin. As might be expected, high amounts of training result in better scores than low amounts of training after a training-test delay (1-day). Reconstruction of perceptual patterns is facilitated by information richness or lack of redundancy found at contour inflection points (Attneave, 1954). For additional views on pattern reconstruction, see Bartlett (1932).

Temporal aspects of complete stimulus presentations are also associated with different responses. Using stimuli interrelated by various mathematical structures, Dienes and Jeeves (1965) found that presenting more complex tasks first, followed by simpler tasks facilitated learning. The explanation given was that the precise (subjective) evaluations given for more complex tasks can then be used advantageously in simpler tasks. Shipstone (1960) additionally indicates that, on pattern conception tasks, subjects resort to more complex rules in direct relation to the number of symbols present.

As reported above, experimental results are associated with both content and structural aspects of stimuli. While findings suggest that familiar items may facilitate performance, Bruner et al. (1958), as reviewed earlier, note that a preference for empirically reasonable propositions (thematic logic) may also negatively affect performance. Responses to incomplete, perceptually-based stimuli are apparently a function of part-whole intrinsicness and the development of perceptual "logic." Inducing patterns on conceptually based stimuli depends partially on subject's age, stimulus complexity, and temporal ordering.

Additional stimulus characteristics requiring experimental distinctions are rule and attribute components. The necessity for such distinctions is illustrated in the next section.

Influence of rules versus attributes. Haygood and Bourne (1965) present evidence that conceptual behavior consists of both rule and attribute learning components. However, according to their research, most investigations have centered mainly on concerns for attributes only with the tacit assumption that rules are unimportant variables. They proceed to demonstrate that combined rule (propositional logic) and attribute (i.e., size, color, form, and number) learning is, in fact, more difficult than (in order) attribute identification or rule learning. An earlier, though less experimentally sophisticated conceptualization of the rule-attribute distinction, is Spearman's concept of relation and correlate induction: relations are mediators of items and correlates are the items themselves. An interesting parallel to rule-attribute distinctions exists in the issue of intellectual skill versus verbal information learning (see Gagné, 1970). While verbal information involves content (attributes) and subject matters, intellectual skills represent rule governed behaviors applicable to a variety of instances.

Related investigations suggest that learning is dependent upon both preknowledge and task properties. Peterson and Beach (1967) suggest that subjects fail to attend to all cells in a correlation task matrix arrangement by generally ignoring the negative information. Even when relevant cues are known, however, propositional rules initially vary in difficulty (Haygood and Bourne, 1965) and non-linear cue-criterion relations (rules) are more difficult than linear relations (Summers and Hammond, 1966).

Deane, Hammond, and Summers (1971) emphasize, in addition to cue and rule variables, a third aspect of task properties, that of cue weighting. They suggest that on linear cue-criterion tasks information about cue weights of differential validity is more helpful than information about cue-criterion rules. Conversely, on non-linear tasks, performance is dramatically improved when the rules rather than the cue weights are known. Furthermore, the poor performance generally found on nonlinear tasks is apparently more a function of inability to apply rather than to acquire knowledge.

In summary, stimulus properties to consider when investigating inductive reasoning include content matter, relational aspects of the content, and relative importance or validity of individual stimulus items. Stimulus structures composing conceptual patterns or specific subpatterns and perceptual units of high information value facilitate what may be, as suggested in the next sections, inherent pattern seeking behaviors.

Research Concerning Organismic Variables

Mentioned earlier, cautiousness reflected in syllogistic reasoning was defined as acceptance of weak, universal, or affirmative propositions rather than, respectively, strong, particular, or negative propositions. Habits were also considered as a major determinant of reasoning products. For Spearman (1923), factors that limit the degree to which cognition actually occurs are: mental energy, memory, fatigue, motivation, and individual potencies. Piaget (see Wadsworth, 1971) suggests that there are four obstacles to the development of logical thought: (a) egocentrism--inability to take or see others' viewpoints, (b) lack of transformation--focusing on successive stages (transduction) rather than the transformation of one state to another, (c) centration--centering of visual attention on limited perceptual aspects, and (d) lack of reversibility--inability to reverse representational actions. Gagné (1970), with a concern for observable conditions, suggests that the following individual differences may affect the problem solving process: (a) store of rules, (b) ease in recalling relevant rules, (c) ease in defining problems, (d) fluency of combining hypotheses, and (e) ability to match specific instances to a general class for solution verification.

Specific findings suggest that (a) children's inductive perceptual reasoning relates to a preference for complexity in art, (b) females have a tendency for deductive reasoning, and (c) males have a tendency toward inductive reasoning (McWhinnie, 1970). A closer look at organismic variables relevant to studying inductive reasoning follows under headings of motivation, cognitive organization, behavioral strategies, and developmental changes.

Influence of motivation. Conceptualizations of motivation often assume the existence of psychological constructs or entities. Gestalt psychology gave early impetus to the notion that thinking was motivated by a need to give conceptual closure. Hull (1952) suggests stimuli become motivational when they become conditioned to responses nearest the goal, and they therefore eliminate unnecessary responses. The belief that cognition has its own intrinsic motivation is expressed by Hunt (1965) and others (Berlyne, 1962; Bruner et al., 1958). For Berlyne, the term "epistemic curiosity" describes conceptual conflicts that activate a need for knowledge to relieve discrepancies in beliefs, attitudes and thoughts. Bruner suggests that information processing strategies are, in part, determined by the degree of strain on memory and inference that is imposed by the task. For Bartlett (1958), intrinsic motivation exists in a zest for adventure and a desire to break out of a "closed system."

Flexibility in reasoning is often related to constructs such as intolerance of ambiguity, dogmatism, authoritarianism, reflection-impulsivity, and risk-taking. Intolerance of ambiguity has as an index the extreme reluctance or readiness to invest meaning into poorly structured stimuli (Frenkel-Brunswick, 1949). Anxiety is considered an important determinant of intolerant behavior (Smock, 1957) resulting in both premature closures and undue adherence to expectancies in ambiguous situations (Smock, 1955). High dogmatic individuals make more errors on valid syllogisms and negative message sources than do low dogmatic individuals (Bettinghaus, Miller and Steinfatt, 1970) and also prefer more consistent and less novel information (Feather, 1969). For high school aged subjects, authoritarianism correlated negatively with deductive reasoning (-.22) and the ability to interpret arguments (-.32) on two tests of critical and analytical thinking (Luck and Gruner, 1970), and children who are conceptually reflective tend to make fewer inductive reasoning errors than do conceptually impulsive children (Kagan, Pearson and Welch, 1966). Risk-taking is apparently a function of identifiable variables (e.g., sex, prior success, and task conditions) and particular individual ways of functioning (Kogan and Wallach, 1964). Individuals may generally be classified, according to Westcott (1968), in a 2x2 table of high and low success and high and low information demand.

The above constructs primarily constitute what is known as personality variables. As mentioned in the beginning paragraph, motivation has cognitive foundations as well. The next section emphasizes the facilitating aspects of cognitive organization and is followed by a section on the various ways individuals approach and solve problems.

Influence of cognitive organization. For Vygotsky (1962), every new stage in the development of generalization is built upon generalizations from a preceding level. Higher concepts, in turn, act to transform the meaning of lower level concepts. Even in productive thinking tasks (see Wertheimer, 1945) where success is attributed to transferring contents to new structures, Vygotsky claims that transcendence of structural bonds requires shifting to a plane of greater generality. It is also this abstraction process (of the ways in which we operate on things) that accounts for the success of mathematical groups descriptive of formal cognitive operations (Piaget, 1970). These abstracted systems similarly characterize personality dynamics for Piaget (See Elkind, 1967).

With an educational orientation, Ausubel (1968) emphasizes the existing aspects of an individual's structure of knowledge. Propositions are supposedly incorporated into cognitive structures, whenever possible, by the inclusion of the most general and inclusive ideas first followed by ideas of lesser degrees. In fact, the purpose of *advanced organizers* is to bridge the gap between what is known and what is to be learned. The function of anchoring ideas in Ausubel's assimilation theory appears similar to Bartlett's (1932) schema. In both, the organization of newly acquired information is a function of past experience. Ausubel's conceptualizations include various information incorporation schemes (e.g., progressive differentiation, integrative reconciliation) but they are beyond the operational requirements of this paper. Instead, an examination of some behavioral strategies for acquiring information follows.

Influence of behavioral strategies. Subjects inducing patterns in series completion tests generally utilize a limited number of operations (e.g., same, opposite, change next column) which are usually based on the notion of simple pattern existence (Simon and Kotovsky, 1963; Simon and Sumner, 1968). The belief is expressed by Simon and Sumner that people have strong propensities to discover and predict patterns in environmentally presented temporal sequences. Beach (1964) reports that in probability learning situations subjects often ignore the independent existence of each trial and, instead, search for real or imagined patterns in a sequence. However, pattern prediction, according to Beach, is somewhat dependent on probability determining parameters and an active process of anticipation rather than mere detection of continuity (Kolers, 1968). The active process involves locating subuniverses of instances and rules (Azuma and Cronbach, 1966) to guide pattern recognition. Investigations into the discovery of mathematical patterns or groups underlying stimulus replacement operations also reveal that some subjects divide the instances into pattern subsections (Dienes and Jeeves, 1965).

Various theories exist to represent search strategies. According to Vinacke (1952), early theories of concept formation emphasized the abstraction of common features with a wash-out of variable features and an active search process of generalizing hypotheses on new instances. These two processes appear, respectively, very similar to the induction and deduction conceptualizations presented earlier. Two current theories (see Klahr and Wallace, 1970) that exist to describe serial completion problems posit either a left to right, single pass process of template building or a multiple pass, piece by piece building of pattern characteristics. Investigating the developmental tractability of these two models, Klahr and Wallace found that neither model is used exclusively by a five-year-old child. The originally used template model was abandoned in favor of the multiple pass (Simon-Kotovsky) model as stimulus complexity increased. On problems requiring hypotheses about pattern differences, E. Johnson (1964) also found that, upon failure of low level scanning for common pattern values, adult subjects utilized more complex strategies involving necessary and sufficient information properties.

A similarity of behaviors for both adults and children does not always exist, however. The next section presents some theoretical and research considerations concerning the development of inductive abilities.

Influence of developmental changes. Piagetian theory claims that productive hypothesizing is dependent on the development of formal (deductive) logic. Prior to age seven, intuition serves as an uncritical substitute mechanism; and prior to the formal reasoning stage, justification is empirically rather than logically based. An additional Piagetian implication concerning inductive reasoning is that children's reasoning is spontaneous: they infer only from particular to particular (transduction) because of a lack of logical rigor.

Related research generally supports the lack of generalization hypothesis. Maier (1936) demonstrates that not until approximately age six can children effectively combine isolated experiences to form new experiences. Additionally, six- to eight-year-old children decrease in correct generalization performances as the abstractness of materials is increased (Long and Welch, 1941); particularization is easier than generalization for children; and generalization is more difficult for children than for adults (Dienes and Jeeves, 1970).

As expected from the nature of growth processes alone, children, when exposed to partial, perceptually-based information, usually demand more information and make more errors than adults (Cox and Fletcher, 1971; Gollin, 1960; Westcott, 1968). Unexpected, however, is the increased relative demand for information by children approximately eight years old than by adjacent age groups in the Cox and Fletcher and Westcott studies. Interestingly enough, at this same age range, Shapiro and O'Brien (1970) found an asymptotic function in the growing (deductive) ability to recognize logical necessity. Also, on tests of creativity, Torrance (1961) found a decreased performance at grades 4-5 in an otherwise steady improvement of the mean number of questions asked. However, for scores reflecting formulation of hypotheses and use of strategies, the plateau in performance was nonexistent (Cox and Fletcher, 1971; Torrance, 1961; Weir, 1964) suggesting the existence of developmental differences in various ability growth rates.

As a cautionary note, Piagetian theory on cognitive development is not without contradictory research findings. Subjects at the college level do not always use formal reasoning abilities, i.e., testing the logical inverse to verify concept classification (Seggie, 1969) or looking for a counter-example to verify deductions (Wason, 1969; Wason and Johnson-Laird, 1970). Use of formal reasoning may be directly related to verifying as opposed to falsifying characteristics and to stimulus difficulty. Failure to search for negative instances may also contribute to an inability of adults to adequately conceptualize the concept of correlation (Smedslund, 1963). Only appearing contradictory, younger subjects may actually perform better than adults on tasks when stimulus differences incorrectly emphasize the child's overdiscrimination or lack of conserving skills (Saltz and Siegel, 1967), or when use of cue dimensions advantageously facilitates younger subjects' rigid attentional facilities (Scholnick, 1970).

To summarize, organismic variables relevant to inductive reasoning include motivation, cognition, behavioral strategies, and developmental changes. While an intrinsic need to accumulate information and reduce cognitive dissonance may exist, "personality" traits often coexist with less than totally objective cognitive operations. The actual process of accumulating information is apparently somewhat determined by the subject's past experience but generally involves isolating, building, or abstracting patterns or subpatterns. Children, however, generally lack the abstraction ability while developmentally proceeding toward a formal system of operation which, in actuality, may never be attained.

A third major category related to investigating inductive reasoning involves subjects' responses. The next section presents the concept of responses as functionally related to experimental conditions not previously discussed.

Research Concerning Response Variables

The vast majority of research cited thus far utilizes experimenter or situationally controlled information presentation. A practice frequently ignored is the more natural way of acquiring information which is exemplified in the scientific method. (From a minimal amount of evidence, subjects form hypotheses and then test those hypotheses.) Westcott's (1968) series completion problems, for instance, allowed subjects to determine the extent of information desired but no variation was permitted in the acquisition sequence. While analyses (i.e., statistics) becomes more difficult when acquisition sequences vary, the results may be more realistic: e.g., performance is interpreted as a function of subjects' hypotheses or developmental differences (see Cox and Fletcher, 1971). In fact, Duncan (1964) presents specific evidence indicating that when discovering the principle for uniting symbols, the best performing subjects were those completely unrestricted in solution attempts. Somewhat similarly, Allender (1969) indicates that children (ages 9-11) formulate and utilize search behaviors from intrinsic motivating factors regardless of external reinforcement. While the insufficiency of research data prohibits presently comparing results of restricted versus unrestricted experimental situations, an awareness and consideration of these methodological problems is not a premature request.

An additional situational factor influencing inductive behavior is the use of training and practice trials. While Gross (1970) suggests that skillful reasoning may result from a general long term rather than short term approach, Wallach and Sprott (1964) demonstrate that young children (age 6-7) can acquire number conservation after extensive training trials. In fact, this latter finding plus Kanaoka's (1969) effective matching of training program and subject's abilities lends credence to a learning theory rather than a maturational approach to cognitive development (see Gagné, 1968). For adults, specific training on related tasks effectively facilitates transfer to new tasks (Dodd, Kinsman, Klipp and Bourne, 1971) and effectively transfers the short-term memory load on both syllogistic and digit span tests to long term memory (Whimbey and Ryan, 1969).

In summary, research findings relevant to investigations of inductive reasoning indicate the appropriateness of examining stimulus, organism, and response variables. Evidence suggests that while a general rule searching or pattern identification trait may exist in varying individual degrees, the trait may interact with (a) personality constructs reflecting openness and flexibility; (b) the structure of knowledge which, in turn, may influence; (c) the searching for and incorporation of information; (d) complexity and temporal presentation of materials; and (e) developmental differences in abilities. While not intended as complete, this review presented factors that may bear on inductive reasoning performances thereby adding clarity to defining induction as a valid psychological entity.

Prior to proposing a model of inductive reasoning, various theories of induction are presented next. While generally not fully developed theories, they do reflect the current state of induction as defined through observable behaviors and information products.

Theories and Status of Inductive Reasoning

As reviewed earlier, theories and models of problem solving posit stages which only indirectly allude to inductive reasoning behaviors. However, several models exist which overtly include induction as a specifiable entity. A discussion of these models and a summary of the current status of induction follows.

Theories of Inductive Reasoning

Five models are presented; two for each type of materials involved (semantic and symbolic) and one unrestricted by stimulus content. For semantic materials, induction involves (a) acts of discriminating and generalizing narrative presentations, and (b) a preparatory model formation stage for organizing and classifying words or phrases. For symbolic materials, induction involves generating a pattern from either (a) the entire letter or number sequence, or (b) from each sequentially presented item.

The Social Studies Inference Test. Developed as part of a project to assess thinking abilities in elementary school children (Taba, 1964), the test assesses both the ability to interpret data and the ability to make inferences. For example, from a descriptive story, a valid generalization is that in non-literate societies occupations follow family lines. A valid inference from this generalization involves predicting the occupation of an unborn male of a particular family. To make a correct inference, the child must discriminate the particulars of a given situation and, through "inductive abstraction," arrive at appropriate concepts and generalizations. Additionally, the process also includes comparing issues and judging data validity.

Schematically, the model for the Social Studies Inference Test is illustrated in Figure 1.

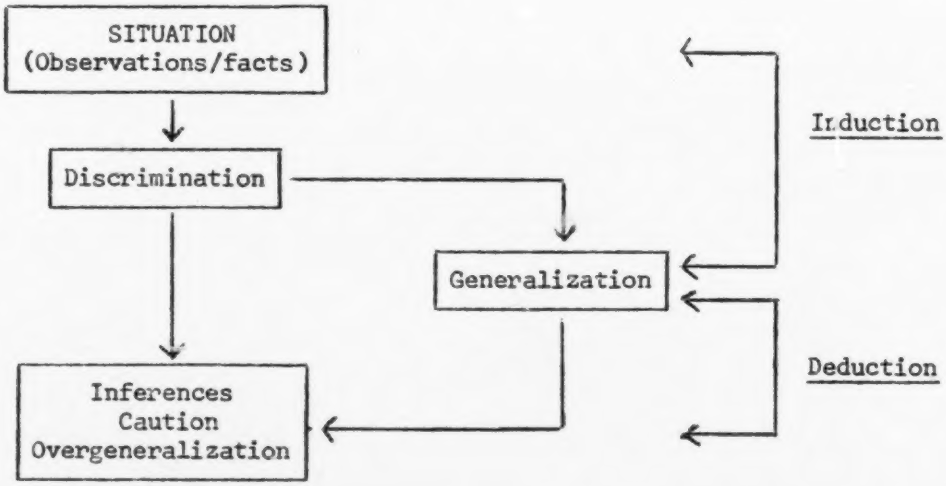

Figure 1. Schematic model of Social Sciences Inferences Test

The Test yields four scores that fit the model labels: (a) Discrimination--distinguishing between events or objects, (b) Inference--includes the logical operations of interpolating, extrapolating, predicting, hypothesizing and explaining, (c) Caution--a tendency to avoid taking a risk, and (d) Overgeneralization--categorizing indiscriminately.

However, induction per se is not conceptually isolated in either the diagram or the test scores. In fact, the Inference score includes the process of hypothesizing which, according to the earlier presented working definition, is an integral part of induction. Also, according to the schematic, generalization exists as an inductive component and overgeneralization exists as a deductive component. The fact that an indiscriminate version (overgeneralization) exists apart from its standard (generalization) casts some doubt on the model's validity. To conclude, a major criticism of this model is that induction is neither adequately defined nor measured, either as a process of generalization or, as preferred, as the products of hypothesizing and generation acts.

Johnson's problem solving processes. D. M. Johnson (1955), summarizing other research, originally suggested that reasoning involves three separate processes: preparation, production, and judgment. Preparation is the dynamic process of getting ready or adopting a preparatory set which controls the production of pertinent responses. Judgment is the evaluation or categorization of an object of thought. Later, however, Johnson (1961) suggests that problem solving involves only two sequential processes: preparation and solution which consist of, respectively, induction and deduction. This time the preparation stage consists of an initial problem formulation; surveying the given material; discriminating certain properties;

and formulating a tentative model or solution to guide the next step. The solution phase consists of searching for an example matching the formulated solution. If an adequate solution is not found, the process is repeated (i.e., the problem is reformulated).

Support for the two-process model was subsequentially derived from experimentation. In a task requiring the organizing and matching of relevant words, induction was defined as selecting only relevant words from a larger list (organizing), and deduction was then selecting a word from a second list to fit the cognitive organization (Johnson and Hall, 1961). Preparation time was isolated and functionally related to the proportion of irrelevant words in the first list. Additional experiments (Johnson, 1962; Johnson, Lincoln, and Hall, 1961) demonstrated that either the induction or the deduction stage time requirements could be altered by the number of materials used to emphasize either respective stage.

Even with this experimental support, however, later research (Johnson and Jennings, 1963) again emphasized three rather than two problem solving processes. As originally defined the processes are again: preparation, production, and judgment. On a task involving story reading, title production, and judgment of a best title, factor analysis confirmed the existence of these three serially related episodes. Related support for three stages comes from Blatt's (1961) study using a Logical Analysis Device (Psi apparatus). Subject's cardiac-rate records identified three critical points in the problem solving process: (a) the point when all relevant information was gathered; (b) the point indicating a behavior change from analysis and question asking to synthesis or information utilization; and (c) the point where the solution sequence began.

Whether consisting of two or three stages, Johnson's formulation of problem solving processes noted the importance of generating plausible hypotheses. Without losing the induction phase, more precise factor analytical specifications could conceivably identify additional stages in the problem solving process. Whatever the number of stages, Johnson's conceptualizations serve as an elementary model of inductive behavior.

Simon and Kotovsky Model. Simon and Kotovsky (1963) propose the existence of a pattern generator to explain how subjects "induct" a pattern description from a sequential pattern segment. The main task of the pattern generator is to detect symbol conditions and to arrange them in the corresponding pattern. From an accumulation of behavioral evidence, the theory codevelopers suggest that subjects first discover periodicity in a sequence and then supply the pattern details by similarly using simple relational operations (i.e., same, next to).

Schematically, performance on a letter series test is represented in Figure 2 (Simon and Sumner, 1968, p. 244).

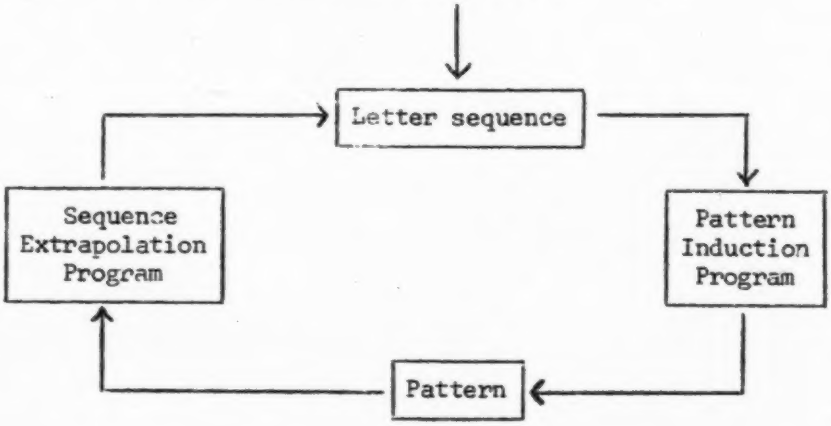

Figure 2. Human performance model for letter series tasks.

Essentially, the subject does two things in the total program: (a) examines the given partial sequence and inducts an appropriate pattern; and (b) from the generated pattern, extrapolates the sequence and generates the appropriate successive symbols. Experiments on letter series completion tests indicate that the above model generally predicts which problems are most difficult for human subjects. The theory additionally indicates that the number of different lists held in memory is more predictive of item difficulty than is the length of the period.

Computer-based, the pattern induction program reportedly adequately simulates test behavior on sequential patterns and is currently being used to analyze cognitive activity of the music listener. The authors report that additional verification studies are planned.

Template building. Klahr and Wallace (1970) present a template building model of inductive reasoning; however, as yet, little evidence is available on model details and empirical validity. Similar to the Simon and Kotovsky model, this information processing model is founded on serial completion problem studies. Basically, subjects supposedly solve completion problems by constructing templates of increasing size until a recurring pattern is found. For example (p. 245):

```
Problem     R G R R G R -

 Step 1     R                       initialize
      2      R                      match
      3     R G                     initialize
      4         R G                 match
      5     R G R                   initialize
      6           R G R             match
      7                 R G R       match
      8                   G         produce
```

Figure 3. Template building procedure for a single attribute (color) with 2 values (red, green).

Most of the S-K model assumptions again apply (see appropriate references for details).

Differences between the two models are worthy of mention, however. A basic difference is that for Simon and Kotovsky the subject keeps track of his position in the alphabet, but in the template model he keeps track of only his generated pattern group rather than the symbols themselves. Additionally, the S-K model makes many passes (left to right) over the pattern, building the description piece by piece, whereas the template procedure constructs the pattern after seeing 2N letters in a pattern of length N. Therefore, the entire pattern may not be seen for template building procedures.

In the only experimental comparison study available, Klahr and Wallace (1970) indicate that, for adult subjects, there is no difference in the predictive ability of either model. As mentioned earlier, the template model is apparently a developmental precursor of the S-K model. Also, as problem complexity increases, template building is evoked less even though the S-K model imposes more of a load on short term memory. Conversely, problem familiarity evokes attempts to embrace the entire problem at once (S-K model). Without further information, analytical comments on the template model presently appear inappropriate.

Fletcher's four stage process model. Developed with the goal of isolating cognitive operations without reference to specific content, the four stage model depicts both the cognitive processes and their sequence of operations in an information processing framework. For Fletcher (1969), research should attempt to "explain" the causes rather than only demonstrate the existence of poor problem solving performance. Hence, he proposes a theoretical model of specific cognitive operations from which experimenters may isolate faulty abilities and suggest optimum training procedures for each ability. The reader will note that, unlike previous models, the expressed ultimate goal for building such a model is the improvement of classroom performance.

A schematic representation of the information processing model is depicted in Figure 4.

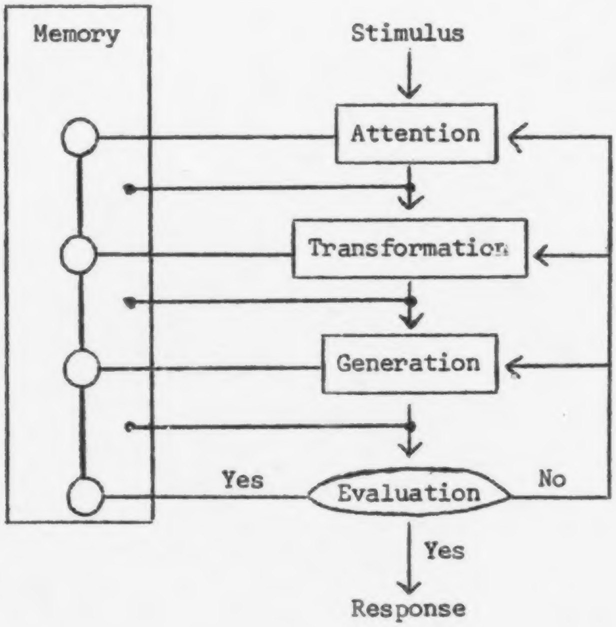

Figure 4. Schematic representation of Fletcher's information processing model.

According to the author, the model was developed by abstracting various process flow diagrams associated with tests of cognition and intelligence. In general, the schematic represents a first approximation to a general model, being more descriptive than functional in nature.

The processes of interest to this paper are those of transformation and generation. The transformation stage refers to active processes which convert cues into meaningful information and the generation stage refers to processes which generate solutions by going beyond the transformed information. Fletcher claims that there is a critical difference between these two stages. For example, in the letter completion task OTTFFSSEN?, the critical stage is not generation but transformation. That is, once the stimuli are transformed the solution follows easily. Without the transformation there can be no logical pattern generated from which to supply the missing letter. Once the letters are encoded to represent the first letter in each of the following words: One, Two, Three, Four, Five, Six, Seven, Eight, and Nine, the problem is embarrassingly easy.

While induction is not specifically mentioned in the Fletcher model, the transformational and generational processes appear relevant. In fact, neither process alone is entirely representative of induction since a pattern cannot be generated without first encoding the information. The question in need of further clarification is whether the generation stage involves only generating a pattern (induction) or whether producing information from that pattern (deduction) is also involved. Even so, the model represents a synthesis of related research from which to pursue further studies.

A summary of the information presented thus far follows. Additionally, viewpoints are offered concerning solidification of induction as a valid and researchable concept.

Status of Inductive Reasoning

The foregoing review, while hopefully representative of issues related to inductive reasoning, may not necessarily be exhaustive. Even so, the wide coverage of research and theoretical issues may elicit criticism concerning the failure to isolate a specific, tightly defined issue. However, the broadness of characterization is in itself the issue: induction is not a conceptually distinct concept. A brief summary serves to reiterate this point.

Summary. Philosophically speaking, the term logic refers to principles by which argumentation and products of reasoning are evaluated. Therefore, while induction is often referred to as generalizing and going beyond the limits of data or experience, its very existence is questioned because of the alogical reliance on inconclusive principles. The induction process (may be labeled hypothetico instead) nevertheless exists as the generative or knowledge-gaining stage in the scientific method. In psychological terms, conceptualizations of induction incorporate an additional ambiguity in addition to that mentioned above: definitions (implicit and explicit) are not distinct. For example, induction exists as insight, as a substitute for logic, as strength or probability values of stimuli, as a passive acquisition process, as a summarizing stage, and as an act of (significantly) utilizing incomplete information.

To assist in clarifying the nature of induction, some stimulus, organismic, and response related variables were reviewed. Both the content of and relationships among stimuli apparently interact with organismic factors on inductive reasoning tasks. Some motivating effects of cognition and personality constructs, as well as the influence of behavioral strategies and developmental changes, were examined. Additionally, while the nature of subjects' responses are functionally related to training and practice trials, little is known concerning the relationship of performance to restrictiveness in strategy utilization.

The few theories and models of induction that do exist operationally contribute to representing induction but not without some conflict. Induction consists of both discrimination and generalization but not hypothesizing and predicting (Taba); induction is the preparatory set which controls hypothesis production (Johnson); induction is the detection of symbols comprising periodicity (Simon and Kotovsky); induction is the building of pattern templates (Klahr and Wallace); and induction possibly involves both transformation and generation processes (Fletcher).

To bring some consistency to psychological conceptualizations of induction, a behaviorally oriented definition was offered. The underlying assumptions regarding the proposed definition are discussed next.

Additional considerations. The underlying assumption of the entire review is that the products of hypothesis generation are fundamentally important for introducing knowledge into our phenomenonalistic and scientific worlds (for empirical validity). However, these inductive generations are neither defined nor researched adequately. Furthermore, the term induction often includes insight and other supranatural processes; and the sometimes substituted term of hypothetico implies a dependence on deductive logic.

To empirically simulate the generation stage of scientific reasoning, appeals to insight and deductive foundations serve no purpose. The proposed definition specifically ties induction to behaviors reflecting categorizational (pattern or model generation) attempts on incomplete information. While examples and tasks most easily represent information figurally (incomplete pictures) or symbolically (letter or number completion tasks), content may similarly exist in semantic (word meanings) and behavioral (human interactions) dimensions. For instance, verbal communication and behavioral patterns are often suggestive of underlying motives. These latter instances, however, reflect more sophisticated inductive behaviors which are beyond the scope of this paper.

A further consideration is that induction should not be confused with inference. In general terms, inference is suggestive of a conclusion or hypothesis that naturally follows (deduction-based) from the given but does not go beyond the information. That is, inference apparently only requires a reinterpretation whereas induction additionally requires producing a subsuming or abstracted concept. Also, while inferences may involve partial information, a higher level rule is not generated as with induction. Perhaps the best description is: similar to transduction (Piaget), inference proceeds from particular to particular without a higher level rule. The distinction between induction and inference may be somewhat unclear, especially on tasks as contained in the Social Studies Inference Test, and admittedly deserves future clarification.

With additional support for the definition of induction, a process model is now proposed. The next section presents research findings to support a model of induction processes which is based on the behaviorally oriented definition.

Proposed Model of Inductive Reasoning

Psychologically based definitions of inductive reasoning do not reflect unified conceptualizations. Strangely enough, while the existence of hypothesizing and generation behaviors is apparently universally accepted, even if only empirically implied, few studies and theories are specifically addressed to these behaviors. The purpose of this section, then, is to propose a model of inductive reasoning which is based on results of related experimental investigations.

Considerations for Model Development

Earlier presented ideas varied from induction as a mechanism for knowing ultimate truths to induction as an observable product. The research examined utilized (a) temporally or spatially presented stimuli, (b) symbolic or pictorial content, and (c) complete or incomplete representations; again reflecting conceptual ambiguities.

The current model, however, defines induction within very specific environmental constraints: the scientific method is the framework in which induction exists. That is, induction occurs when a rule or pattern is formulated to explain information which is not totally complete. Examples include: (a) inventing the Periodic Table of Chemical Elements, (b) inventing classifications of biological organisms, (c) hypothesizing lawful relations underlying planetary motions, and (d) generating psychological constructs to describe phenotypically varying behaviors. For initial investigatory reasons, however, verifiable instances are the only concerns at present.

Additional boundary conditions for defining induction follow. From the nature of scientific reasoning, the task situation emphasizes spatial rather than temporal patterns. While evidence generally accumulates over time, data are analyzed in spatial rather than temporal schemes. There are exceptions, of course (e.g., musical patterns), but these exceptions are generally eliminated by the next consideration--stimulus incompleteness. The data or stimuli considered must be incomplete, thus automatically eliminating instances where the underlying rule explains the existing data only, no more or no less (e.g., "what is the rule that combines the following numbers?"). Also, behaviors eliminated by this incompleteness requirement involve those associated with concept formation/attainment as a function not of incomplete information but of incorrectly hypothesized component rules and attributes. A third major consideration involves the use of symbols rather than pictures. While using pictures as stimuli is not inappropriate, the reasoning product is more often perceptually rather than conceptually based. Tasks more representative of real life circumstances should involve stimulus content other than figural (i.e., symbolic, semantic, or behavioral). The fourth condition implied throughout is that induction involves proposing a rule to handle the data but does not involve generating appropriate stimulus characteristics. In fact, hypothesizing the nature of stimuli may be more deduction than induction if based on an existing or assumed rule or pattern. Lastly, as mentioned earlier, inductive behavior is derived from the behavioral performance of human subjects with no recognition given to supposed unconscious processes.

The model of inductive reasoning is clarified when proposed in relation to deductive reasoning. Therefore, the next section illustrates the process relationship of induction and deduction.

Model of Inductive Reasoning

To repeat the earlier proposed working definition, induction is the generation of a reportable hypothesis from only some members (as given) of a class, scheme, or pattern to describe the whole or at least some larger portion thereof. The definition stands as offered with an additional clarifying comment. The hypothesis must subsume the data but the data can not subsume the hypothesis, thereby making the model only a sufficient rather than a necessary and conclusive product as in deduction. Because of the requirement for insufficiency of the given information, the generated hypothesis must be a product both of the externally given information and the additional, filling information that is supplied by the subject. Hence conclusions are only sufficient (i.e., not necessarily conclusive) and vary by subject.

The combined processes of induction and deduction are schematically depicted in Figure 5.

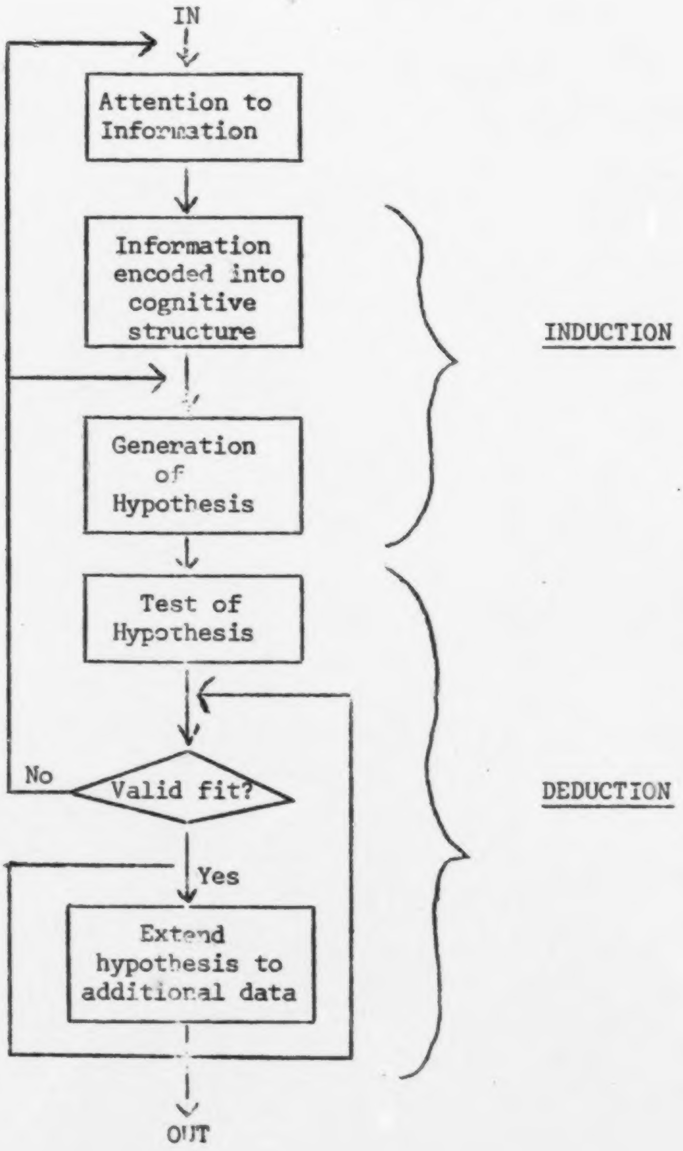

Figure 5. Process model of inductive and deductive reasoning

The model in Figure 5 serves as a framework in which to view inductive reasoning but is not offered as a proposed theoretical construction. The reader may, in fact, note some resemblance to various theories discussed earlier (i.e., Bloom, Dewey, Johnson, Fletcher, Simon and Kotovsky, Taba).

The issue of importance in Figure 5 is the dual stage induction process. The act of inducing a pattern or rule from partial evidence involves: (a) incorporating relevant information into cognitive structures, and (b) generating a hypothesis to subsume the existing data. Supportive evidence for these two stages follows in the next section.

Support for a Dual-Stage Theory of Induction

Perhaps the best way to describe the two induction stages of interest is with the phrase, rule making process. Gestaltists, protesting the over-simplified mentalistic attitudes of man, demonstrated the crucial role of structures and organizational properties both in stimulus configurations and in observer's responses. More recent research suggests that man actually structures impinging stimuli into patterns and subsequently predicts from these models. Neimark (1970), in proposing an information processing description of cognitive development, suggests that information is (a) first coded and stored by templates and models, and (b) later produced from templates and models. While the existence of predicting or hypothesizing behavior is somewhat self-evident, verification of model building processes is a more remote operation. As reviewed in the next section, however, model building processes are dependent on psychological drives, cognitive organizations, and capacity restriction.

Cognitive encoding. Various theorists and researchers (e.g., Ausubel, 1968; Bruner, Goodnow and Austin, 1958; Guilford, 1967; Johnson, 1944;

Kolers, 1968; Miller, Galanter, and Pribram, 1960; Neimark, 1970; Shipstone, 1960) have implied or suggested the existence of subjective models of the universe. In fact, one theory of cognitive development (Piaget) is founded on the process of building internalized action and behavior structures. Additionally, as mentioned earlier, various reports support the notion that individuals search for patterns or subpatterns in sequentially presented information. Psycholinguists (e.g., McNeill, 1966; Miller, 1962) describe "deep" sentence structures as abstracted features which subjects induce from the arrangement of sentence words. From these abstracted models which subsume many sentence forms, subjects generate sentences previously unencountered. Bourne (1970) suggests that conceptual behavior is explainable as a hierarchy of knowledge wherein systems represent abstracted rules, and so on down to objects representing abstracted attributes. In addition, Dienes and Jeeves (1970), and Dodd et al. (1971) demonstrate that acquisition of an intuitive stimulus structure (e.g., a logical truth table) facilitates interrule transfer. Thus, the pervasiveness of psychological model building or abstracting is demonstrated in this sample of appropriate literature.

Perceptually based research findings also support the existence of psychological model building. Attneave (1955) suggests that a perceptual mechanism may function to reduce redundant patterns into simpler, less redundant forms. Posner and Keele (1968), employing mathematically constructed pattern distortions, suggest that subjects abstract and store both the schema and some additional but unknown information to later facilitate recognition of the pattern prototype. While implying that the abstracted information may be of a verbal nature (from introspective reports), no definite conclusions were drawn. Furthermore, the pattern abstraction apparently occurs during the learning rather than during the test trials (Posner and Keele, 1970).

The motivating forces for abstracting or encoding were mentioned earlier. Briefly, motivation derives from cognitive dissonance or stress and is related to personality constructs. Bourne (1970) specifically suggests that human behavior is better represented as a hierarchical rule-following system rather than as a linear, cause-effect mechanism. The ability to solve serial completion problems has a basic part in human needs (Klahr and Wallace, 1970) and persists even in the presence of noise (Simon and Sumner, 1968).

Additional motivating forces may result from capacity restrictions. As noted previously, Simon and Kotovsky (1963) suggest that the number of subpattern lists inversely affects serial pattern acquisition, and Posner (1965) more precisely claims that the amount of information processed determines the speed of performance. In either case, the limiting factor is short term memory capacity which can, however, be relieved through training: the work load is partially shifted to long term memory (Whimbey and Ryan, 1969). Miller (1956), also implicating the restrictive capacity of immediate memory (7 ± 2), proposes that chunking and recoding are alleviational and thus motivating processes for increasing the cognitive store of information. A direct extension of the Miller hypothesis, Shipstone (1960) presents experimental findings indicating that pattern conception also functions under the same capacity limitations. In general, the mean number of pattern categories generated in sentence sorting tasks ranged between five and seven.

The act of model building, abstraction, or recoding thus appears to be a basic psychological function. Research directed at verifying the existence and importance of model building as applicable to inductive reasoning is scarce (Shipstone is a notable exception), but related research gives positive support. Existence of the second stage of inductive reasoning, hypothesis generation, is so naturally evident that supportive research for its existence appears unnecessary. The emphasis in the next section is, therefore, on the relationship of hypotheses to inferred cognitive structures.

Hypothesis generation. The nature of hypotheses is often used to infer the underlying cognitive organization. In fact, the evidence to support Piagetian theories consists almost entirely of subjects' hypotheses. When learning patterns or even letter series such as the alphabet, perhaps the developmentally earliest type of organization is some type of rhyming or chanting. On more complex items, mnemonic systems aid the invention of meaning even when there is none. Tulving (1962, 1964) notes that once organizational recall occurs, the organization remains (even when stimuli are restructured) which, in turn, facilitates the learning of new words.

The task of relating performances to the quality of hypotheses is not generally included in induction experimentation. The task of objectifying the quality of hypotheses is naturally a difficult chore. Cox and Fletcher (1971) note that on incomplete picture tasks subjects aged four to eight do not generally vary in number of different categories verbalized. Torrance (1961) notes a developmental difference in children's questions; children in grade one to three ask "why" questions but the older children ask "what" questions.

A more extensive discussion on the nature of hypothesizing behavior appears repetitious. Many studies already discussed use as their dependent measure the subjects' verbalizations. Therefore, rather than duplicate earlier efforts, the reader is referred to appropriate studies of individual interest.

In summary, a two-phase process of induction was proposed with an emphasis on the first phase--information encoding. The subject apparently builds a model of the "universe" from which he generates new information. The second phase, hypothesizing, reflects the subject's internal model and, as a behavioral product, is used as a dependent measure in inductive reasoning experiments.

With a review and clarification complete, the next section includes some implications of inductive reasoning research. Implications of both a psychological and educational nature are examined.

Implications of Inductive Reasoning Research

The importance of investigating inductive reasoning behaviors cannot be overstressed. Inductive reasoning is the process by which theories are generated and thereby from which knowledge is gained. Most investigations of cognition emphasize deductive reasoning to the sorry neglect of inductive reasoning. This practice is true in spite of national concerns addressed to how people, and especially children, learn. Induction must surely play a part in the learning process but few investigations emphasize or even delimit inductive processes and behaviors. A closer examination of the implications of inductive reasoning research follows.

Psychological Implications

The functional considerations discussed earlier suggest various implications for future laboratory research. The interaction of stimulus and organism variables imply that one variable cannot be studied without consideration of the other. For example, the numerous relationships among motivating factors and stimulus content necessitate measuring or controlling as many factors as possible. Additionally, the experimental situation interacts with other "independent" variables such as age and sex which cannot be manipulated as a within-subject property. Even so, both laboratory and "real-life" research should consider the conditions under which subjects are willing or not willing to take a risk and the motivational reasons underlying subjects' behaviors. For example, Guilford (1967) presents at least eighty cognitive variables where interactions are possible; Kogan and Wallach (1964) identify numerous variables related to risk-taking behaviors; and Westcott (1968) describes the relationship between success and information demand as well as cognitive and personality correlates of these measures. A similar request for obtaining as many relevant measures as possible is also currently voiced by educational evaluators.

Experimental research mentioned earlier also reflected both the infrequency and difficulty of isolating various stages of reasoning. In fact, only a few studies (e.g., D. M. Johnson) even attempted process delineation. However, the notion central to this paper is that process delineation should occur even though present methodology offers no immediate solution. More emphasis is needed on psychological process isolation instead of performance characteristics (e.g., time, error scores). It is conceivably possible that similar performances across subjects may result from individually different process utilization. In keeping with the previous paragraph, precise stimulus, organismic, and response specificity could prevent overlapping process occurrence. Specific to this paper is the request for research which functionally isolates inductive and deductive processes. Use of stimulus diversity and truncated solution processes may aid in isolating various within and across subject differences. After process delineation occurs, the next research step is determining differences across individuals within each component process.

Specific psychological variables worthy of further investigation include the rule-following behavior of subjects. That subjects possess a need to follow rules was, in fact, suggested as a replacement to the premise that subjects are cause-effect motivated organisms. Perhaps S-R mechanism development precedes later rule-governed behavior. How these two motivational constructs developmentally interrelate is worthy of extensive investigations. Studies in perceptual behavior often emphasize the recoding of information into more usable forms and, studies in the cognitive realm emphasize the rule or structure determining approach of language acquisition. For some theorists, cognitive activity may best be characterized as following the rule of least effort. The reorientation of psychological investigations to rule rather than stimulus determining processes would certainly alter present conceptualizations. If there is a substitution of rule-governed behavior for earlier stimulus-determined behavior, then the substitution contingencies deserve examination. Furthermore, interesting investigations would involve the interaction of personality variables (e.g., dogmatism) with rule-governed behaviors. Also of interest is the rule versus attribute learning distinction. Research which attempts to functionally isolate the joint processes of rule and attribute learning may very well lend credence to inductive-deductive distinctions.

An additional reorientation of psychological research involves the role of short term memory in reasoning processes. Generally, information processing theories stress the role of the short term memory holding capacity. However, many studies mentioned herein emphasize the role of short term memory as an active information processing unit. In fact, it was the processing rather than the storage capacity which determined subject's performance rates. Investigations are needed to determine the relationship of the holding and processing capacity of short term memory. Developmental changes in this relationship also appear worthy of investigation. Also, both rule following and processing capacity considerations are important in relation to most inductive reasoning circumstances. That is, while we receive information which is often incomplete, this incomplete information is also highly redundant. Optimally, the redundant information must be abstracted (rule formation) to avoid exceeding information processing limitations. How information is abstracted and how this ability may be improved deserves further consideration.

An implication of vast importance is that I.Q. scores correlate poorly with incomplete information task performances (see Dienes and Jeeves, 1965, p. 119). For these authors, error scores correlated higher with information extrapolation (induction) scores than did I.Q. scores. Hence, the dubious nature of I.Q. test applicability is again questioned. Interesting and educationally significant studies would involve investigating the feasibility of replacing I.Q. tests with incomplete tasks and determining the subsequent predictive validity.

Educational Implications

We must "learn guessing (Polya, 1954)." If one of our educational goals is to develop independent thinkers then we must teach subjects how to productively hypothesize from incomplete information. The opportunity for inductive reasoning occurs regularly; from theorists and researchers pushing at the frontiers of knowledge to the consumer theorizing the pattern of price fluctuations. In spite of its pervasiveness, few programs teach inductive reasoning per se.

Moreover, the practice of using inductive teaching methods is not without criticism. For example, Bruner's (1961) eloquent theories of discovery learning are contested by researchers of a more experimental orientation. Gagne and Brown (1961) indicate that requiring subjects to reinstate concepts of future importance via guided discovery techniques is more facilitating than pure discovery learning. Ausubel (1968) suggests that while generic coding provides a stable anchorage for related material, the coding cannot regenerate lost content. In non-academic settings, however, discovery learning may be the only process available. That is, the individual must generate his own theories with only very little structured assistance. Therefore, perhaps the emphasis in teaching should be on independence and functionality of the subject's inductive abilities rather than on maximum performance in controlled situations. To provide the best of both worlds, subjects could be taught heuristics and strategies for developing their own anchoring ideas and formulating reinstateable concepts. Furthermore, rather than attempting to mold creative intellectual individuals, the emphasis should be on teaching for autonomous and productive individuals.

When to begin inductive training is perhaps the next question to ask. From the little research available, it appears that younger subjects are less constrained at making guesses or hypotheses than are older subjects. Perhaps training should start at the early ages with the expressed purpose of retaining the freedom of generation which later apparently becomes inhibited. The transition stage noted at approximately eight years of age definitely demands further investigation. Whether training should be postponed or increased during this stage is an interesting question. How many school years to devote to induction training is also an unanswerable question at this time. Obviously, there are many unanswered questions that are particularly relevant to teaching inductive techniques to school-age children.

A further consideration involves the relation of training to organismic variables which are generally free of developmental changes. Most research toward this issue is concerned with aptitude-treatment interaction effects. It is highly conceivable that individuals vary in their ability to achieve better under one method of instruction than they do under another. As might be expected, individuals generally make more errors on inductive instrumental methods than on deductive methods (Koran, 1971). Unexpected, however, was the equal time requirements and transfer effects noted for both methods. However, these results should not be considered without a concern for individual abilities. King, Roberts, and Kropp (1969) suggest that subjects high in either inductive or deductive abilities score higher on respectively oriented test materials. Thus, for educational purposes, individual differences should be determined on aptitude-treatment interactions. Each individual could conceivably require different instructional treatments based on his present aptitudes. Whether the aptitude-treatment effects change over utilization time should also be investigated.

For all the implications, few educational programs specifically emphasize the teaching of inductive reasoning. The program, "Man: A Course of Study" requires subjects to think divergently and to raise questions that are open-ended. While children supposedly come to recognize patterns of thought and behavior, the emphasis is on acquiring an appreciation of man as a fantastic and complex creature. The AAAS curriculum, "Science, A Process Approach" similarly requires subjects to perform hypothesizing and inferring operations. In these and other related programs, however, the specific process of induction is not conceptually isolated and examined. In fact, most instances demand inference rather than induction operations. The emphasis is on deducing consequences rather than on making conjectures. Of even greater importance is the lack of empirical (research based) justification for any of these programs. The existence of program construction without research support is somewhat understandable, however, in view of the amount of experimental evidence available.

In summary then, induction is a vital reasoning process for man's progress. However, the process is only incidentally acquired and not specifically taught. Furthermore, research findings are largely irrelevant to curriculum development needs. That is, the variable effects of stimulus properties and organismic variables are unknown. When to begin instruction, for how long, and to what extent, is just not known. The present review paper conceptualized a data base which should indicate the research emphasis necessary for eventually constructing an inductive reasoning curriculum.